NTRD Technical Monthly January FY18

Nuclear Technology Research and Development

Prepared for
U.S. Department of Energy

March 15, 2018

NTRD-PAC-2018-000472
INL/EXT-18-44878

CONTENTS

FIGURES

ADVANCED FUELS CAMPAIGN

MATERIAL RECOVERY AND WASTE FORMS DEVELOPMENT

NUCLEAR TECHNOLOGY RESEARCH AND DEVELOPMENT TECHNICAL MONTHLY JANUARY FY18

ADVANCED FUELS CAMPAIGN

ADVANCED LWR FUELS

LWR Fuels

- **[LANL]** A set of U_3Si_5 crystal growths have been completed, varying crystal pull rate, rotation rate and crystal size to evaluate the effect of crystal growth parameters on the quality and uniformity of the resultant crystals in order to determine the best set of growth conditions to produce crystals suitable for use as reference materials. The reference crystals can then be used for a variety of experiments to produce a consistent data set to inform modeling and simulation. Characterization of these crystals is ongoing. (K. McClellan)
- **[LANL]** A ^{10}B-loaded liquid scintillator neutron detector with an active area of 43 cm and capable of 500 MHz event rate was installed at the 60m station of the FP5 beam line at LANSCE. The detector, previously used for parity violation experiments in the 1990s, has excellent neutron detection efficiency of 95%, 85%, and 71% at neutron energies of 10, 100, 1000eV, respectively. The 4 cm liquid scintillator tank is viewed by 55 photo-multiplier tubes. In collaboration with the nuclear physics group at LANSCE, state-of-the-art data acquisition based on CAEN digitizers was installed. Using the Time-of-Flight (TOF) method to measure neutron transmission as a function of energy at the pulsed LANSCE neutron source. The detector will be used to investigate changes in the neutron absorption resonance profile. Based on the well-understood but rarely exploited theory for resonance profiles, profile changes depend on the phonon density of states in the solid and can be explained by effects such as Doppler-broadening due to temperature changes or differences in the crystallographic/chemical environment of the absorbing nucleus. Meister et al. reported distinctly different profiles of the ^{238}U resonance at 6.67 eV in metallic uranium, ceramic UO_3, and gaseous UF6 and provided a qualitative explanation by different approximations of the phonon spectra. While few applications of this phenomenon are reported, modern DFT calculations allow accurate prediction of the phonon density of state that could be merged with this experimental technique to uniquely and non-destructively characterize nuclear fuels.
- Partial calibration of this system (32 out of 55 PMTs working, minimal background reduction efforts) has occurred and preliminary data on several systems with ^{238}U nuclei (metallic uranium, U-10Mo, UO_2, U_3Si_5) were collected with some of the data shown below (Figure 1). Besides connecting modern solid state physics calculations with a unique experimental technique, the capability will complement the non-destructive pulsed neutron-based material characterization at LANSCE by allowing characterization of the isotope density in a nuclear fuel with CT reconstructions based on previously demonstrated energy-resolved neutron imaging. Installation of a 1 mm collimator to collect neutron transmission data for a detected feature, e.g. an inclusion, allows us to obtain much higher quality neutron transmission data than is possible with the borated glass multi-channel plate detector used for imaging. This effort is in preparation of a milestone report later in the year to assess the potential of neutron absorption resonance profile analysis as a characterization technique for nuclear fuels (L. Vo/Kansas State Univ., A. Losko/LANL, N. Borges/WPI, and S.Vogel/LANL).

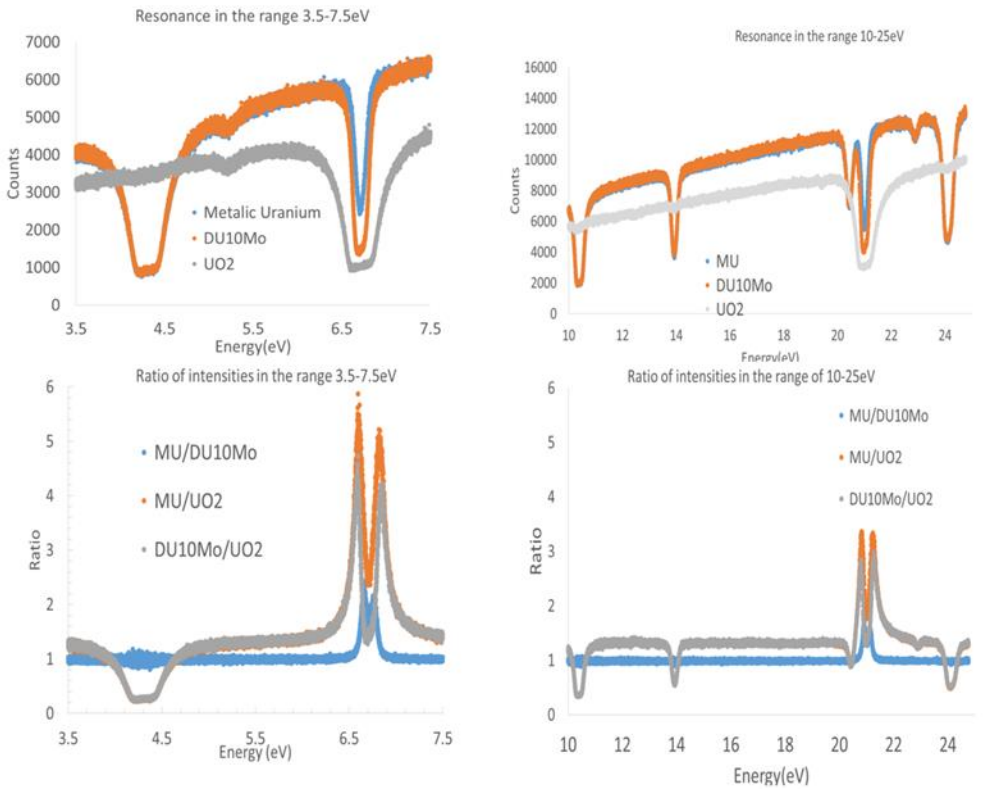

Figure 1. Top left: Tantalum (internal standard) and uranium resonance at 4.28 and 6.67eV, respectively. Top right: Tantalum resonances at 10.36, 13.9, 20.3, 22.7, and 23.9eV, and ^{238}U resonance at 20.9eV. Bottom graphs are ratio resonance profiles.

- **[LANL]** Preliminary nanomechanical testing at room temperature on high density UB4 and UB2 fabricated through a collaboration with Rensselaer Polytechnic Institute has been performed. Elastic modulus and hardness were determined. Other elastic properties will be measured and compared to the results obtained at nanoscale via resonant ultrasound spectroscopy. These data are the first such measurements for uranium boride compounds, considered as possible components in high density ceramic composite LWR fuels (U. Carvajal-Nunez).
- **[LANL]** Previous studies performed by AFC have shown that exposure of U_3Si_2 to hydrogen-containing and steam environments resulted in pulverization of the fuel, which was hypothesized to be due to the formation of a hydride phase. However, changes in microstructure were performed post-facto, at room temperature, and in the absence of hydrogen. It is therefore of great interest to combine such post-facto techniques with in-situ measurements in order to evaluate the kinetics of hydride absorption and to determine the microstructural evolution as a function of exposure to hydrogen. To that end, a new method of in situ structural determination under hydrogen atmospheres at elevated temperatures has been deployed. U_3Si_2 powder was exposed to hydrogen gas and X-ray diffraction was performed in a time-resolved manner to capture phase changes as a function of time. The first patterns at room temperature and 400ºC were collected and will be used to further refine the technique. This data will elucidate the thermodynamics and kinetic information on hydriding of U_3Si_2 as relevant to service and accident behavior of this fuel form. (A. Shivprasad).
- **[LANL]** The feasibility of using neutron resonance spectroscopy (NRS) to accurately measure temperatures without introducing error from the lattice structure of UO2 samples has been investigated. Experiments were carried out at the Lujan Centre using energy resolved neutron imaging at flight-path 5 to characterize the resonance patterns of stoichiometric and non-

stoichiometric UO2 powder samples up to 500 ˚C. Previously, Meister et al. have shown that the resonance patterns of different chemical compounds of uranium, uranium metal, UO3 and UF6, differ from one another [1] yet it is still unknown if the changes in stoichiometry of UO2 translate to changes in the resonance patterns. This study will provide conclusive evidence of the effect of crystal structures on NRS measurements of UO2. The goal here is to use NRS as a thermometry method, in a second set of flash sintering experiments, if proven that differences in crystal structures do not affect the measurements (E. Kardoulaki, LANL).

[1] A. Meister *et al.*, "Doppler broadening of 238U neutron resonances in crystal lattices and molecular gas compared with the free-gas approximation," in *Nuclear data for Science and Technology*, 1983, no. 2, pp. 968–970.

LWR Core Materials

- **[LANL]** Specimens were polished from C26M FeCrAl tubing to analyze the grain size distribution, local texture (EBSD) and nanohardness. Data was pulled together in a L3 report showing the initial microstructure of this material after tube forming operations. (S. Maloy)
- **[ORNL]** HT9 tensile specimens manufactured using power-blown additive manufacturing (AM) were tensile tested at room temperature, 330°C, and 550°C after post-build heat treatment and with no treatment. Tensile tests were performed to determine baseline properties of AM-produced HT9 compared to traditional wrought properties. Initial data analysis indicates strength and ductility of AM HT9 are as good as or better than wrought HT9. (N. Sridharan/K. Field)
- **[ORNL]** AM produced 316L with Yttrium additions were characterized using electron microscopy to determine the oxide dispersions within the specimens. Preliminary characterization shows a heterogeneous distribution of coarse oxide particles indicating a refinement in the composition and/or build parameters are needed for further optimization. (N. Sridharan/S. Dryepondt)
- **[LANL]** Analysis is underway on C26M FeCrAl alloys after oxidation at 300-600C up to 2000h. Thin foils are being cut out with Focused Ion Beam to accurately measure the oxide thickness corresponding to these oxidation conditions. (A. Nelson)
- **[ORNL]** Preliminary data was procured on the precipitation of the detrimental alpha prime phase and dislocation loop segregation in neutron irradiated C35M using atom probe tomography from a NSUF-RTE activity. The data shows segregation of Al to dislocation loops, (Figure 2 below), which could provide new insights into the hardening of neutron irradiated FeCrAl alloys when compiled with further data in the FeCrAl cladding handbook. (D. Zhang/K. Field/S.A. Briggs)

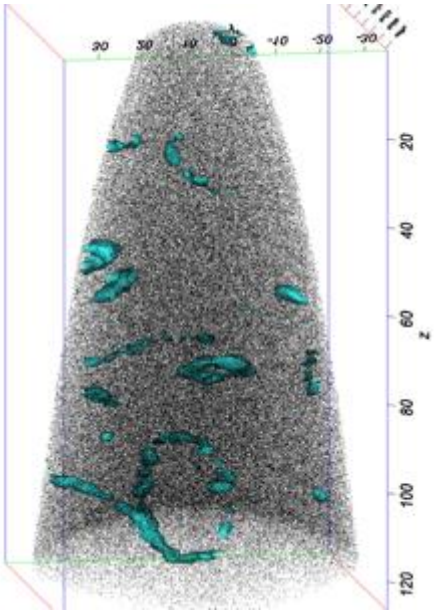

Figure 2. APT reconstruction for C35M (Gen. II FeCrAl) neutron irradiated in HFIR to early-of-life light water reactor (LWR) conditions. Figure is in nm; cyan surfaces represent iso-concentration surfaces showing Al enrichment to dislocation loops within the microstructure.

- **[ORNL]** Evaluation of yttrium effect on high-temperature microstructural stability in Gen. II wrought FeCrAl alloys was initiated. The alloy Fe-10Cr-6Al-1Nb-0.22Y (wt.%) with average grain size of ~100 µm exhibited stable grain structure with very little grain coarsening during annealing at 1200°C for up to 120 min. Preliminary atom probe tomography characterization revealed significant amount of yttrium segregation at the grain boundaries which could effectively increase the solute dragging and prevent grain coarsening. Such microstructural stability could be beneficial for preventing potential property deterioration attributing grain coarsening after exposure at high-temperatures. Further investigation, including the effect of yttrium contents on microstructural stability, is currently in progress. (Z. Sun, Y. Yamamoto)
- **[ORNL]** Production of Gen. II wrought C26M FeCrAl alloy tubes (Fe-12Cr-6Al-2Mo base) through tube drawing process is in progress. There is no change in the expected delivery date (on March 2018). (Y. Yamamoto)

LWR Irradiation Testing & PIE Techniques

- **[INL]** Physics analysis for ATR cycle 168B-1 was completed and the thermal analysis is in the technical check segment of the process. The physics analysis demonstrates that the experiment has been, and will continue to operate within the ATR safety basis parameters set in the Experiment Safety Analysis. (D. Dempsey)
- **[INL]** Neutronic, thermal/hydraulic, and structural analyses were completed and an invitation for a January 29, 2018 design review kickoff meeting was sent. Fabrication of "low risk" ATF-2 (Fuel Test) components and weld development are in progress. (G. Hoggard)
- **[INL]** Optical microscopy continued on uranium silicide samples from ATF-1. Lessons learned from sample preparation of un-irradiated uranium silicide were transferred to hot-cell sample preparation resulting in superior quality. (J. Harp)

LWR Fuel Safety Testing

- **[INL]** Transient prescription analysis is progressing in earnest. The first transients are occurring at the TREAT reactor and these actual results are providing excellent input for the prediction analysis. (D. Dempsey)
- **[INL]** Drawings for the Secondary Can have been completed. Subsequently, subcontractor bids for Secondary Can fabrication are being pursued with award expected in the next few weeks. (D. Dempsey)
- **[INL]** A study on how PCF changes with core temperatures for steady state low level power operations where it is estimated that the core temperature will not go beyond 120 degrees Celsius demonstrated negligible difference in PCF if the core temperature remains under 50 degrees Celsius. Percent change in PCF beyond that temperature begins to be significant with a change of approximately 7% evaluated at 120 degrees Celsius. Comment resolution including literature review and updates to discussion and MCNP plot figures has also been completed. PCF was evaluated at temperature increments of 20 degrees Celsius from room temperature to 120C. Nuclear data cross sections at those specific temperatures were generated that can be applied to CAL programmatic PCF analysis for comment resolution. (J. Schulthess)
- **[ORNL]** A TMI-1 spent fuel segment planned for in-cell irradiated LOCA testing (FY18 L2 Milestone) has been cut to 12" and leaching of the first 0.5" of fuel on each side is complete. A small met sample has been harvested for measurement of the oxide layer. Once the oxide layers are removed the specimen will be transferred to the east wing for welding and assembly of the LOCA test rig. (K. Linton)

LWR Computational Analysis & Fuel Modeling

- **[BNL]** One aspect of evaluating the performance of ATF under accident conditions is an uncertainty analysis to identify and quantify all potentially important parameters that impact the code predicted figures of merit, such as the peak cladding temperature (PCT) and the amount of hydrogen generation. An effort has been initiated to set up an uncertainty analysis framework. The approach is to use the TRCAE-DAKOTA interface in SNAP (a graphical user interface to perform TRACE runs) to create uncertainty job streams, executing TRACE runs and generating DAKOTA reports (including, e.g. PCT distribution and importance ranking of parameters). (L.-Y. Cheng)
- **[BNL]** Full core equilibrium calculations require "optimization" of shuffling scheme to achieve more reasonable power distributions. Figure 3 sketches the previously used shuffling scheme and a proposed new shuffling scheme. (A. Cuadra)

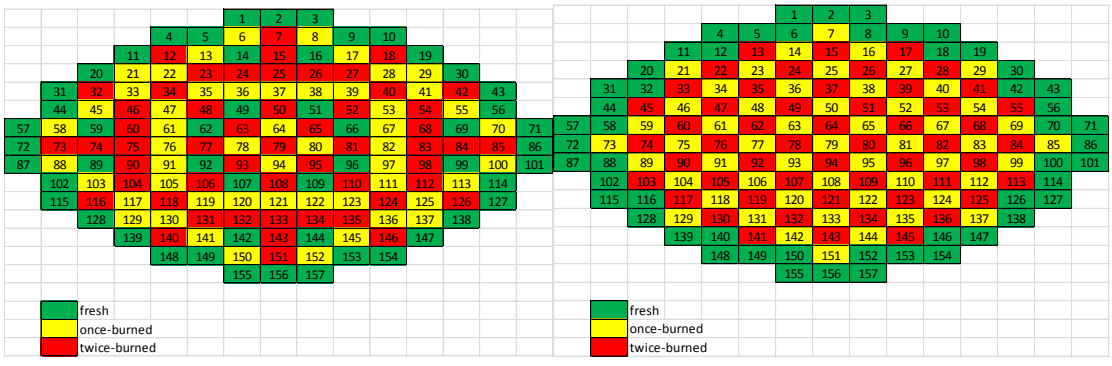

Figure 3. Fuel shuffling schemes under consideration.

- **[INL]** The modeling planning effort is zooming in on an investigation of mechanical performance of cladding coatings for ATF fuel and impact of the coatings on the fuel performance aspects other than corrosion.(P. Medvedev)
- **[ORNL]** Recent efforts on FeCrAl cladding have focused on improving solution convergence and implementing suitable boundary conditions in order to simulate a loss-of-coolant-accident for a boiling water reactor using the BISON fuel performance code. This work uses a full-length BWR fuel rod, and is intended to provide a comparison of the accident performance of both Zircaloy and FeCrAl cladding. This includes demonstrating high-temperature constitutive models and oxidation models. Our preliminary results show the ongoing efforts toward simulating a LWR fuel rod under LOCA conditions. Future work will consist of improving solution convergence for high temperature constitutive models, activating oxidation models, and comparing the response of FeCrAl cladding with Zircaloy. (B. Wirth)
- **[ORNL]** Deformation Analysis of SiC/SiC Channel Box for BWR applications continued. The temperature dependent swelling of SiC/SiC under irradiation may cause lateral bending in the channel box, as has been shown for SiC/SiC cladding [Singh et al., 2017]. This potential issue with the SiC/SiC channel box is being analyzed through finite element calculations focused on determining the deformation of SiC/SiC channel box under the BWR conditions. A finite element model was set up and temperature boundary conditions, obtained through thermal-hydraulic calculations, and neutron flux boundary conditions, obtained through neutronics calculations, were implemented into the model. The initial calculations show significant lateral bending (~several millimeters) in the channel box. (B. Wirth)
- **[ORNL]** Detailed neutronic and thermal hydraulic models were enhanced for two GE14-like BWR fuel assemblies with silicon carbide fiber/silicon carbide matrix channel boxes. Each model features seven distinct axial zones. Each zone is distinguishable by fuel enrichment, gadolinium content, coolant/moderator density and void fraction, linear power, and the disappearance of partial length rods in the upper zones. Final checks and updates to the models were made in the past month.

  The models to obtain a discretized neutron flux distribution in the channel box for neutron energies greater than 0.1 MeV. This gave radial neutron flux distributions in the channel box at seven axial locations in the BWR fuel assembly. Flux values were provided as a 3D distribution over the full length of the fuel assembly. Calculated flux values are in the range of approximately 1.0x1013 to 2.5x1014 neutrons/cm2-s.

  There is significant non-uniformity in both the temperature and flux boundary conditions of the channel box. Updated temperature and flux data for both simulations are being used for a mechanical analysis of stress and channel box distortion. The corresponding contour plots are shown in Figure 4-Figure 7. All four sides of the channel boxes are shown. (N. Brown)

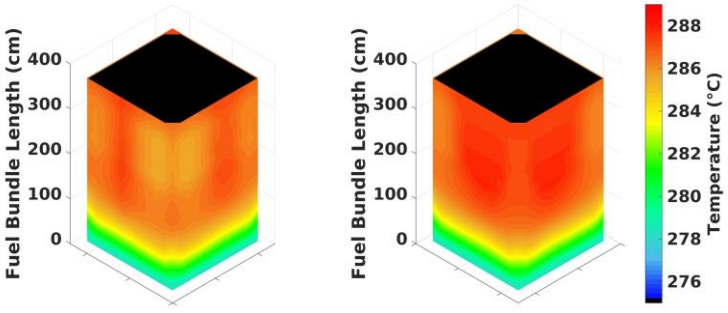

Figure 4. Simulation 1 channel box temperature distribution.

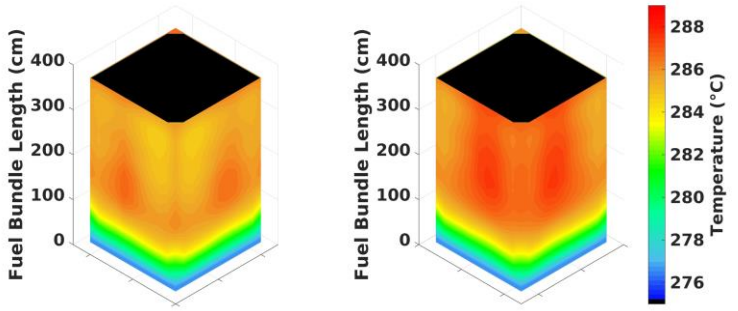

Figure 5. Simulation 2 channel box temperature distribution.

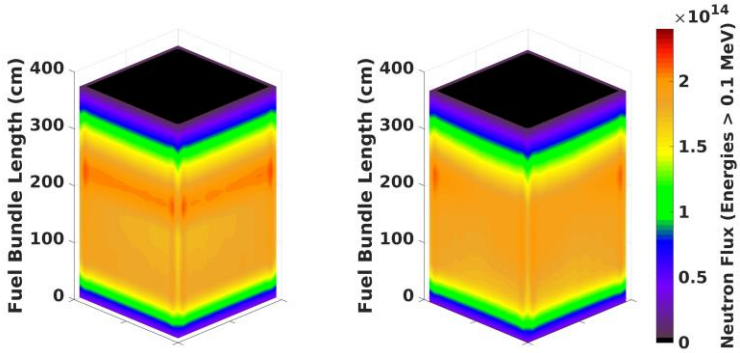

Figure 6. Simulation 1 channel box neutron flux distribution.

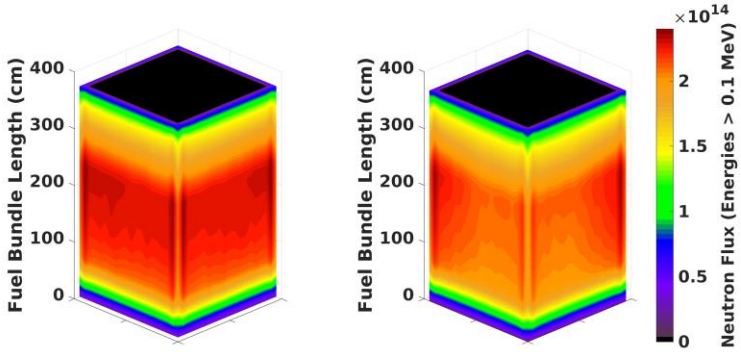

Figure 7. Simulation 2 channel box neutron flux distribution.

Industry FOA

- **[INL]** The following items were completed in January. (P. Wells)

  Project Documentation

  1. Detailed project schedule was completed and validated with BEA senior management.
  2. The project risk register was completed.
  3. The project schedule was submitted to Westinghouse for concurrence.
  4. The environmental checklist was completed and submitted to DOE for approval.

5. The glovebox acceptance test plan was completed.
6. The fire hazards evaluation for the HDF glovebox was completed and submitted for review.

Equipment Procurement

1. The factory acceptance test for the sintering furnace was completed.
2. The sintering furnace was shipped to INL.
3. A second autopress was purchased to speed pellet production.
4. A V Blender was purchased and received.
5. A 15 ton chiller for the sintering furnace was purchased.
6. An air dryer for the EFF Atlas Copco air compressor was purchased.

EFF Facility Modifications

1. The argon dewar placement is complete.
2. The facility modifications are roughed in to a point pending receipt of the sintering furnace, arc melter, and chiller. Once equipment arrives, the services will be completed.

Fabrication

1. The final pellet drawing was received from Westinghouse.
2. Testing was completed to determine the cause of branch cracking issues in the ATF-2 pellets.
3. A second review meeting and tour was held to evaluate fabrication improvements.
4. Training has begun for five new technicians.

ADVANCED REACTOR FUELS

AR Fuels

- **[INL]** Two level 3 milestones were met under the Advanced Fabrication Development work package; Development of the MOX development plan and Characterization report of co-extruded U-Zr alloys. The MOX development plan will be used to set development priorities for the next several years as far as MOX development. Initial work in FY17 readied the facility for further MOX work by modifying, testing, and operating the stoichiometry control system. Following the development plan the next series of experiments will be performed in order to increase final density of the sintered pellets. It is expected that this will be accomplished by incorporation of new pressing hardware and testing of various binding agents. Experiments will be performed to determine the repeatability and predictability of stoichiometry based on the controlled provided. As part of this work a method of determining MOX stoichiometry also needs to be developed. Finally, a stable low density fuel fabrication process will be developed.

  The second milestone met was to submit a report on the characterization of the co-extruded Zr/U-Zr fuel alloys. As stated in previous highlights, a zirconium canned U-10Zr and U-6Zr fuel alloy has been extruded. Characterization included visual inspection, radiographic inspection, and metallography. Visual inspection showed a consistently extruded rod with no visible fuel. However, due to worn die, the surface finish and final dimensions of the fuel rod were not well characterized. Metallography showed an equiaxed grain structure in both alloys in the radial direction, and an elongated structure in the longitudinal direction as could be expected in the as-extruded direction. However, the U-6Zr longitudinal structure was much less visibly elongated. Both alloys showed a definite zirconium concentration gradient with the area next to the zirconium can material being much higher in zirconium than the interior portion of the fuel. (R. Fielding)

- **[INL]** The ε, λ, and χ phases U-Zr-Fe phases were seen in used EBR-II fuel in the regions affected by fuel cladding chemical interaction. These phases have been observed in post irradiation examination,

but have not been characterized. Understanding the crystal structures of these phases will aid in further understanding and mitigating fuel cladding chemical interactions (FCCI) in advanced fuels. As part of this effort four of these ternary phases have been fabricated and have undergone SEM characterization (Figure 8). The samples have been annealed and will undergo further x-ray diffraction and SEM characterization in the annealed form. One method of controlling the FCCI is by adding alloying elements to control the migration of the lanthanide elements which contribute to and enhance FCCI. An alloying agent currently being investigated is tin. In out of pile characterization of fresh fuel containing tin, a 11Zr-37Sn-52Ln phase has been observed. This phase supports the idea that tin is a good candidate for controlling FCCI in fuels. (R. Fielding)

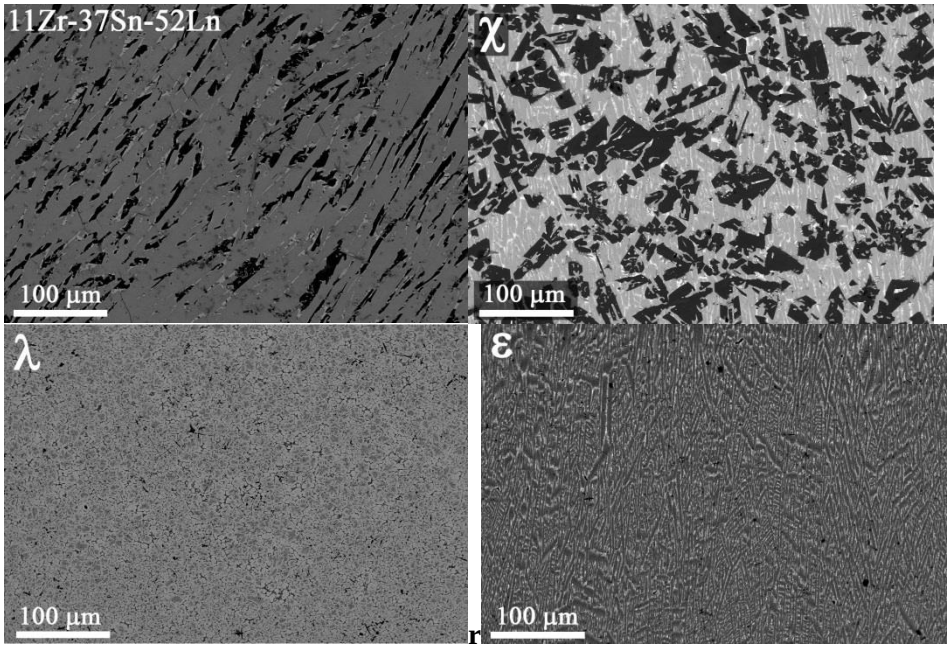

Figure 8. SEM Characterization.

- **[INL]** One new feature of the 2018 update to the Metallic Fuels Handbook will be incorporation of triangular plots generated with Origin software. These plots will make it easy to visually compare and understand data from complex alloys in ways that are impossible with two-dimensional plots. Figure 9 below shows six representations of the gamma solvus based on experimental data from different sources, including INL data from previous revisions of the Handbook. All of these figures should be considered preliminary, but are examples of material that may appear in the 2018 revision of the Handbook. The first four figures (left to right; top to bottom) are ORIGIN contour plots showing the temperature of the gamma solvus in ternary U-Pu-Zr alloys calculated using data from different sources. All of these plots have the same data for elements and binary alloys, obtained from journal papers. Individual data points are indicated by small black dots. With the exception of the plot showing only INL data, there is a large overlap between data in the plots. The last two figures (left to right; top to bottom) show previously published contour maps of the gamma solvus. Differences between the representations of the gamma solvus indicate that further high-quality measurements from a range of compositions are needed.(C. Papesch)

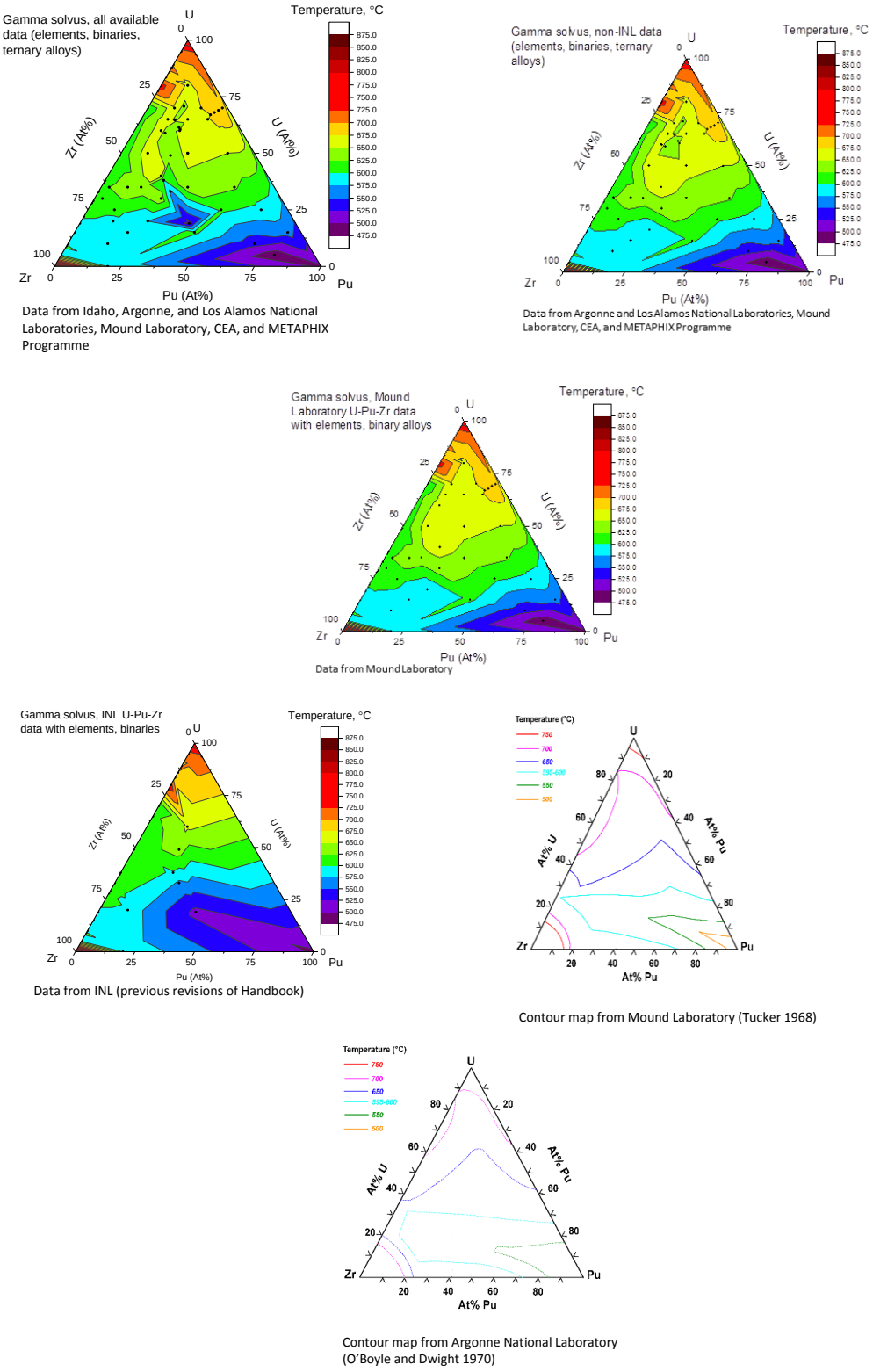

Figure 9. Six representations of the gamma solvus based on experimental data from different sources, including INL data from previous revisions of the Handbook

- **[INL]** A journal paper was accepted for publication in *Nuclear Technology* on January 29, 2018, authored by Dawn Janney and titled "Experimentally known properties of U-10Zr alloys: A critical review." Proofs are forthcoming.
- **[INL]** Thermal diffusivity and expansion vs. temperature of U-13 wt% Zr – 4 wt% Pd were collected upon heating to 1000°C. The slope changes in thermal diffusivity correspond to phase changes and/or lattice parameter changes in the alloy that affect thermal conductivity (Figure 10).

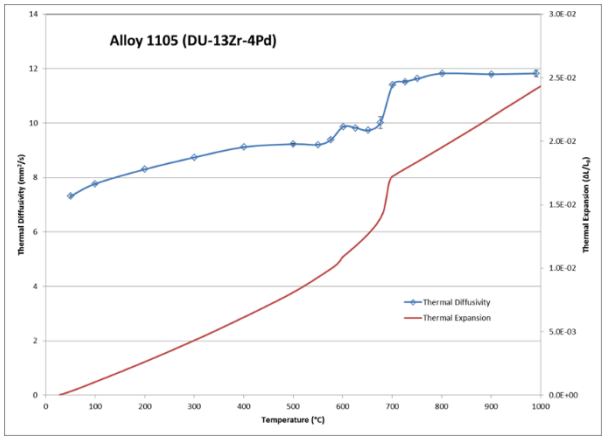

Figure 10. Thermal diffusivity and expansion vs. temperature of U-13 wt% Zr – 4 wt% Pd.

- **[INL]** A tour was given to the new DOE Idaho representative of MFC including FMF and the AFCI and TRU breakout gloveboxes to explain capabilities and projects under this work package. (L. Squires)

AR Core Materials

- **[LANL]** Discussions continue with the CEA to prepare to ship MATRIX specimens that were previously irradiated in the Phenix fast reactor up to 75 dpa. CEA has drafted an implementation agreement and we will discussing agreeable terms through teleconferences in February. (T. Saleh)
- **[PNNL]** Preparation for investigating the tensile properties and microstructure of the three newly fabricated 9Cr ferritic-martensitic steels began. Specimens for atom probe investigations have been made, and tensile specimens are being machined. (M. Toloczko)
- **[PNNL]** Barrier hardening estimates of neutron irradiated MA957 were begun. The observed increase in yield strength of the irradiated specimens is consistent with a barrier hardening coefficient of 0.2 for the alpha-prime precipitates and 0.5 for the YTiO oxide particles. Effects of solution strengthening haven't been considered yet, and their contribution may reduce the magnitude of the barrier hardening coefficients of the alpha-prime and oxide particles. The barrier hardening coefficient of 0.2 for alpha-prime is a little higher than but generally consistent with the estimated value from analysis of neutron irradiated ferritic-martensitic steels that we have examined. (M. Toloczko)
- **[LANL]** Rods of 14YWT produced at ORNL from the FCRD-NFA1 powder were pilger processed successfully at CEA into tubes with a final wall thickness of 0.5 mm, 1.0 cm diameter and length of 95 cm. This is part of the DOE-CEA bilateral. Tubes were received at LANL this month. In collaboration, rods were hydrostatically extruded from 14YWT that was made by CEA. Three tubes were produced that are each 10 inches in length and 7 mm diameter. Tubes were packaged to send to CEA for analysis. (S. Maloy)

- **[ORNL]** Neutron scattering experiments were conducted at the HB-2B beam line at HFIR to measure the residual stresses produced by FSW in the butt joint of two 1 mm thick 14YWT plates. A sample of 14YWT that was annealed for 30 min. at 1000ºC was also analyzed in the neutron scattering experiments. The measurements on the annealed this sample are for determining the strain strain-free lattice parameter "d-zero" value of the {112} peaks that were measured in the current and in previous the neutron scattering experiments. This will permit more accurate calculations of the lattice strains, which are used in determining the residual stress. Overall, sufficient neutron counts were obtained from the two orientations of TD and ND (Transverse and Normal Directions), but the neutron scattering signal-to-background noise (i.e. neutrons) was too small for the RD orientation. The significance of the current neutron scattering experiments of the FSW stir zone and the previous ones on the hot-rolled plates will permit a more accurate assessment of the magnitude of residual stresses that is caused by friction stir welding. (D. Hoelzer)
- **[ORNL]** An extended 4-page summary paper for oral presentation was submitted to the Nuclear Fuels & Structural Materials for Next Generation Nuclear Reactors (NFSM 2018) embedded topical meeting of the American Nuclear Society (ANS) 2018 Annual Meeting in June 17-21, 2018. The summary title is "History and Outlook of ODS/NFA Ferritic Alloys for Nuclear Applications" and covers the history in development of ODS/NFA alloys and relevant results that provide an outlook on their application in advanced nuclear reactors such as fast reactors. (D. Hoelzer)
- **[PNNL]** As part of the program to fabricate tubing from difficult-to-fabricate materials, the PNNL rolling mill is being modified so that it can perform pilgering of tubes. The design of the rollers needed to perform pilgering is well underway; material for the rollers has been procured and mandrels are being procured. A Solid Works drawing of the rollers has been developed, and this model is now set up so that it can be transferred to the machine shop electronically. As developing the final design for the rollers may be an iterative process, the ability to transfer design modifications electronically will be a significant advantage. (R. Omberg)
- **[PNNL**] Information is being assembled for the PNNL milestone report due 31 March 2018. The report will focus on, and only focus on, the modifications to the rolling mill as needed to develop a pilger mill. The milestone is: M3NT-18PN020302052 'Modify rolling mill and perform initial pilgering operations to develop process parameters'. (R. Omberg)
- **[ORNL]** Dual-ion irradiated T91 was procured from University of Michigan to serve as a surrogate material for characterization testing prior to further execution of testing on ACO3 HT9 duct material. (K. Field)
- **[PNNL]** Transmission electron microscopy (TEM) analysis was completed for the two HT-9 steels (i.e., original and N-doped) in as-quenched and fully tempered conditions, which is part of the effort to improve high temperature fracture resistance of HT-9 steels. These two heat-treating conditions represent extreme cases, respectively, for the highest strength and for the highest ductility. An optimum mechanical property is supposed to be found between these two cases. The TEM images confirmed that finer and generally more planar type laths were formed with the traditional composition (heat-3). The as-quenched microstructure consisted of only lath martensite or subgrained structure and high density dislocations, and carbides and clear lath and subgrain boundaries appeared after tempering treatment at 750 °C for 1 hr. The morphology of laths (or ferrite subgrains) indicates that the hardenability by producing the fine quenched structure has become lower in the heat-4 with N-addition. (T.S. Byun)

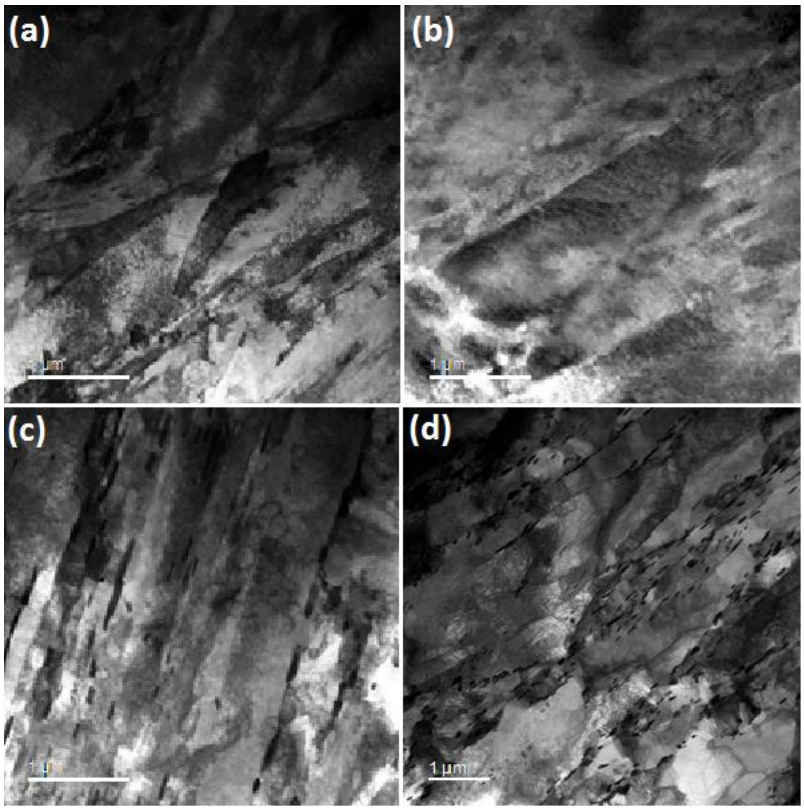

Figure 11. Bright field TEM images of HT-9 steels with (a) original composition (heat-3), in as-quenched condition, (b) N-addition (heat-4) in as-quenched condition, (c) original composition (heat-3) in quenched and 750ºC tempered condition, and (d) N-addition (heat-4) in quenched and 750ºC tempered condition.

AR Irradiation Testing & PIE Techniques

- **[ANL]** A module of SAS4A code was modified to analyze the Advanced Burner Test Reactor (ABTR) transient with annular fuels. It is noted that negative reactivity from a relocation of molten fuel is an important factor to ensure inherent safety of SFR, and the relatively high pressure of bond sodium locked in the fuel slug is one of the driving forces of the molten fuel relocation in a solid fuel. Since there is no bond sodium in the annular fuel, a different behavior of fuel motion is expected with annular fuel. In the ABTR transient analysis, the original solid fuel was simply replaced with annular fuel, which has the smeared density of 75%. The preliminary simulation results show that the central void of the fuel closes early in life, with the hottest axial region completely closed at ~1.0 at% local burnup. Afterward, the pin behaves in a manner similar to the solid fuel in the axial regions where the inner cavity is closed. Additional activities are underway to evaluate the annular fuel performance with higher smeared density (A. Karahan, Y. Miao)
- A paper titled, “Assessment of AmBB Performances in Fast Reactors” by G. Aliberity. T. Kim, and S. Hayes, was submitted to an international conference on Reactor Physics (PHYSOR 2018), which will be held in Mexico, April 22-26, 2018. The paper summarizes the AmBB (Americium Bearing Blanket) transmutation performances in the 1500 MWth ASTRID reactor with a small addition of fissile material and moderator pins. (G. Aliberti)
- **[INL]** Physics and thermal cycle analysis are in the technical check segment of the process. Completion is expected on February 7, 2018 which will support an early ATR startup. (D. Dempsey)

- **[INL]** Neutron radiography was performed on EBR-II historically irradiated fuel. One pin contained irradiated U-20Pu-10Zr with Ga. Galium is commonly used to stabilize Pu, but it also can embrittle steels. This irradiation was intended to show if Pu containing Ga could be directly recycled into nuclear fuel and burned in sodium fast reactors. The other fuel pin is a variation on U-20Pu-10Zr that will be used to create samples for eventual electron microscopy examination of this historically important fuel form.
- **[INL]** Non-destructive testing of AFC-3C and AFC-3D was completed with a series of gamma spectrometry exams that mapped the location of different fission products in these rodlets. These rodlets will now move on to fission gas release measurements. (J. Harp)
- **[ORNL]** The first specimens from HFIR irradiation capsules have been successfully removed from the fused sample holders, mounted, and prepared for SEM survey to identify features of interest. Initial discussions on analysis strategy and what information will be targeted have been held with the project microscopist. (G. Helmreich)

AR Fuel Safety Testing

- **[INL]** A literature review was begun for historical transient fuel performance, metal fuel qualification and testing plans, and relevant regulatory documents. (D. Wachs)

AR Computational Analysis & Fuel Modeling

- **[INL]** Modeling porosity as a field variable that is fully coupled to temperature has been shown to realistically capture the important effect of porosity on typical fuel performance calculations. The approach demonstrates specifically, how power generation, thermal conductivity, fuel temperature, and pore velocity itself are all affected by porosity. A reasonable prediction of central void formation and growth is also demonstrated. Furthermore, the importance of multidimensional (e.g. offset fuel) effects in fuel pellets can now be evaluated. These modeling considerations should play a vital role in licensing. (P. Medvedev)
- **[LANL]** The implementation of the recently developed gas release model has resulted in step changes in the stress field. The root cause of this problem is being researched before we begin development of the fuel crack model and find a satisfactory resolution for the numerical approach including meshing strategy. An elementary model has been developed for MOOSE and ABAQUS codes and results are being compared to identify any issues. (C. Unal)
- **[LANL]** Material model development is underway including a fully implicit stress update algorithm and tangent modulus with the effects of rate-independent plasticity, time hardening creep, thermal expansion and swelling effects. Strain is assumed to be small, and an additive decomposition of the total strain rate is assumed:

$$\dot{\varepsilon} = \dot{\varepsilon}^{el} + \dot{\varepsilon}^{th} + \dot{\varepsilon}^{sw} + \dot{\varepsilon}^{pl} + \dot{\varepsilon}^{cr}$$

  A J2 von-Mises plasticity is used with a radial return mapping algorithm. Creep is assumed to be in time-hardening form. Plasticity, creep and thermal expansion algorithms have been verified using several single element level tests through implementation in an ABAQUS user subroutine. Current work is underway to add the mechanistic swelling model to the existing material model and derive the stress update and tangent modulus. (C. Unal)
- **[LANL]** The stress solve in MOOSE has been compared to ABAQUS by using a number of single element tests under simple loading configurations in a 2D-RZ coordinate system. The conditions in the test were increasingly more complex starting from simple linear elastic to more complex plastic and time hardening creep with varying parameters. The stresses obtained from MOOSE and ABAQUS were in good comparison, at least on the element level (Figure 12). (C. Unal)

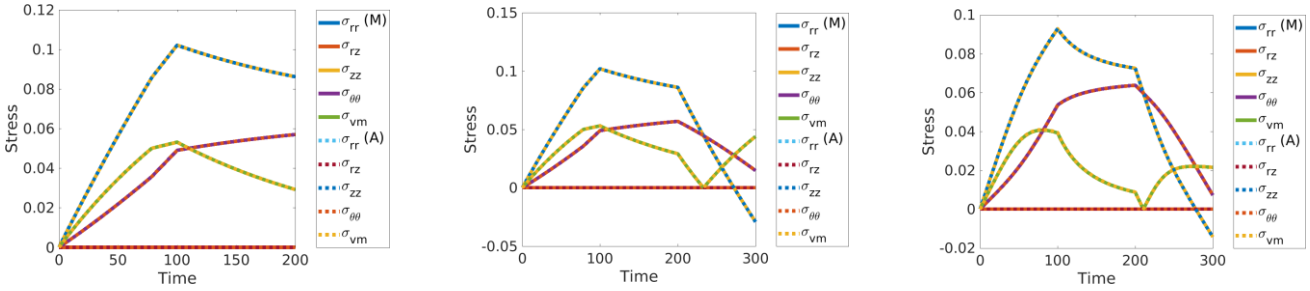

Figure 12. Stresses obtained from MOOSE and ABAQUS.

- **[LANL]** During February the mechanistic fuel swelling model will be implemented and a proto-typical simulation in 2D-RZ will be completed. The effect of porosity will be linked to other material properties (e.g. thermal conductivity, specific heat capacity, mechanical properties) and compared to simulation results from BISON. The comparisons will be extended to include the effect of temperature and include full pin simulations with standard numerical convergence studies (e.g. mesh refinement, non-linear and linear solvers, etc.) We expect to develop a numerical approach that is satisfactory in order to develop the crack model and expect to finalize the swelling model in the next two months. (C. Unal)

CAPABILITY DEVELOPMENT

CX Fuels

- **[INL]** We continue to investigate glove box compatible sputter coaters for use with the TCM. Several questions were answered by inspecting the sputter coater currently installed in a glove box at IMCL. Although more expensive than other coaters, glove box compatibility makes this the best candidate. We are requesting more information on options from the vendor. A beam profiler was used to investigate the quality of the beams exiting the fiber collimators and microscope objective. The pump beam exiting the collimator does not appear to be Gaussian. A different collimator was used and preliminary measurements indicated better consistency when measurements are taken in orthogonal directions. Work on the software improvements and bug fixes has also begun. Inconsistent stage movement has been corrected. The new multimode optical fiber feed through for the thickness monitor has been received and will be tested in the coming weeks. (D. Hurley)

For more information on Fuels contact Steven Hayes (208) 526-7255.

MATERIAL RECOVERY AND WASTE FORMS DEVELOPMENT

PROCESS CHEMISTRY AND INTEGRATION

- **[INL]** A novel aminopolycarboxylate reagent incorporating the component of structural pre-organization for the complexation of trivalent f-elements has been synthesized at ORNL and delivered to INL for thermodynamic characterization. The protonation constants and the stability constants for the complexation of Nd3+, and Eu3+ with N-picolinate-N,N′,N′-ethylenediaminetriacetic acid have been determined adding to the library of structurally modified aminopolycarboxylate aqueous holdback complexants characterized for enhanced An3+/Ln3+ differentiation. The reagent shows very attractive thermodynamic features to continue the drive towards efficient An3+/Ln3+ separations using low pH aqueous mixtures.(P. Zalupski)
- **[INL]** A manuscript describing the radiation chemistry studies of hydrophilic DGAs was submitted to the journal, *Solvent Extraction and Ion Exchange* with the FZJuelich collaborator Andreas Wilden (Germany) as the lead author. This work describes the products and rates of DGA degradation under irradiation in water, and compares to previous results for the dodecane-soluble DGAs. The manuscript also contains information related to acid hydrolysis of the water-soluble DGAs. These data are important because water-soluble DGAs are proposed for use as hold-back reagents in several American and European fuel cycle proposals. Their radiolysis and hydrolysis rates have not been previously reported. (B. Mincher)
- **[INL]** An irradiation campaign to measure the possible radiation protection effect of octanol for TODGA was also competed. This work is in support of FY18 milestone M3NT-18IN030102033, and is also conducted in collaboration with FZJuelich. The goal is to quantitatively measure the dose constants for loss in TODGA with dose as a function of octanol concentration, since previous work suggested that TODGA is protected by octanol. These samples are currently being analyzed for TODGA concentration by LCMS.(B. Mincher)
- **[INL]** A second campaign to irradiate the monoamide DEHBA was also completed. These samples were analyzed for DEHBA concentration and it has been determined that the rates of DEHBA degradation are different for different solution conditions. In our previous DEHiBA work it was reported that dose constants were invariant with the presence or absence of the aqueous phase, or air sparge. This was true within analytical uncertainty. However, with improvements in the analytical methods being used, and irradiation to higher absorbed doses, slight variations in degradation rates have been detected. The samples are also currently being analyzed for degradation products. The irradiated solutions have also been used for U/Pu solvent extraction experiments. These samples are currently being analyzed by ICPMS. This work is being conducted in collaboration with CEA Marcoule, and supports milestone M3NT-18IN030102035. (B. Mincher)
- **[ORNL]** The milestone report (Report NTRD-MRWFD-2017-000155; ORNL/SPR-2017/533) for this effort was submitted on 1/31/2018. This report describes the techno-economic analysis of advanced molecular sieve zeolite membranes to separate and concentrate tritiated water (HTO) from dilute HTO-bearing aqueous streams. The analysis considered the tritiated water separation performance of SAPO-34 and LTA membranes and energy requirements for the process. Compared to the SAPO-34 membranes, LTA zeolite membrane performance both with respect to separation factor and permeance was superior and encouraging. LTA zeolite membranes were selected as the preferred option for comparison with the Combined Electrolysis and Catalyst Exchange (CECE) process for the concentration of tritiated water from dilute HTO-bearing aqueous solutions. It is estimated that the total energy cost to process 10 L/min of tritiated water for the membrane cascade system is substantially lower compared to the CECE process. A preliminary capital cost estimate for the membrane based system and the CECE process is also reported.

- **[ORNL]** Several system improvements were made to improve the accuracy of permeance measurements. (B. Jubin)
- **[ORNL]** The pressing of two pellets made from 40v% WO_3 and 60v% Cu was reported last month. The sintered specimen pressed at high pressure was axially cut and polished. Figure 13 shows the polished surface and Figure 14 is a backscattered electron images showing a continuous copper phase with encapsulated particles that display some inter-particle contacts. Figure 15 shows the energy dispersive spectroscopy (EDS) analysis of the same region for Cu, W, O, and C. The carbon is probably an artifact due to alcohol residues used for cleaning of the surface. One additional pellet of this type is being prepared and a surrogate UNF powder was prepared by ammonia precipitation and several pellets using this powder will be prepared next. (B. Jubin)

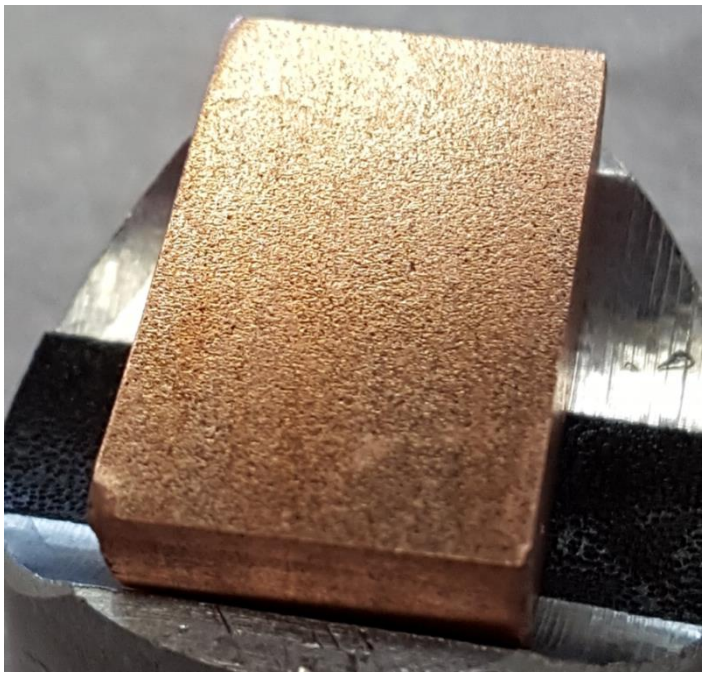

Figure 13. Pellet pressed at high pressure.

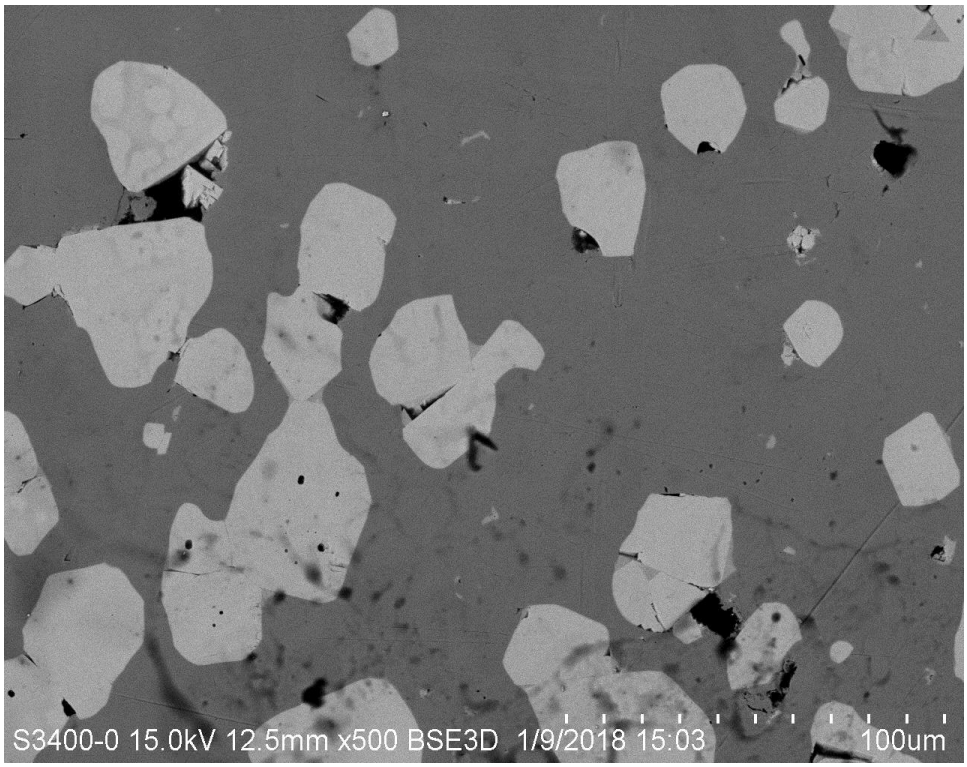

Figure 14. Backscatter electron image of the section pellet pressed at high pressure at 500X.

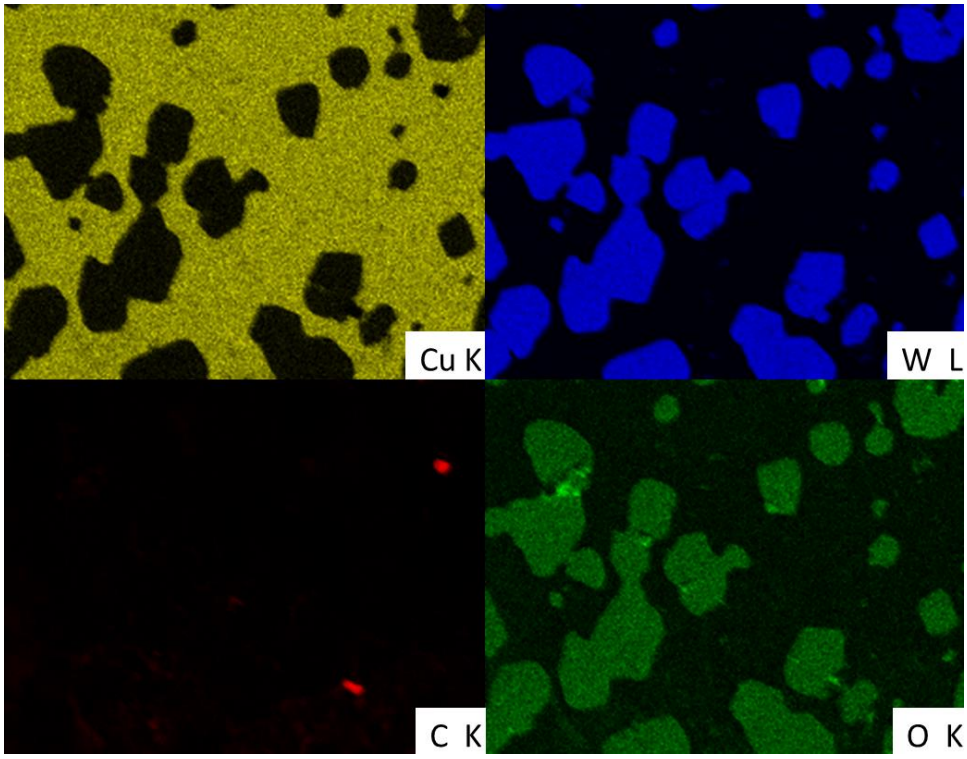

Figure 15. Energy dispersive spectroscopy images of the section pellet pressed at high pressure (same area as shown in Figure 2).

SIGMA TEAM FOR ADVANCED ACTINIDE RECYCLE

- **[INL]** The autoreduction of Am(V) is being studied to supplement previous reports concerning Am(VI) reduction. Since Am(V) is more stable to reduction by the radiolysis products of Am, longer data collection times were used, and the information is being collected at varying nitric acid concentrations. The first complete dataset was collected at 6.5 M HNO3. It reveals that at least two processes occur; at short times on the order of 10 hours, Am(V) reduction is fastest, and is accompanied by the growth of Am(VI). This is clear evidence of Am(V) disproportionation. Disproportionation has long been suspected, but can now be observed quantitatively. At longer observation times, the rate of Am(V) reduction slows, possibly because it is being regenerated by the reduction of Am(VI) produced during disproportionation. In very exciting results, the mass balance for total Am decreases with time, but then appears to be recovering by the end of the data collection. This is attributed to Am(IV), not observable by UV/Vis but expected from Am(V) reduction. The recovery of the mass balance at long times was predicted prior to the actual data collection and is due to the ability to see the Am(III) and Am(V) species still remaining, with a lower contribution due to Am(IV). This is strong evidence for the presence of Am(IV) in nitric acid solution, which has not been previously reported in the literature. (B. Mincher and T. Grimes)

WASTE FORM DEVELOPMENT AND PERFORMANCE

Electrochemical Waste Forms

- **[ANL]** Scoping tests and analyses were conducted with material DPF1 that was provided by PNNL as the initial iron phosphate glass waste form made with dehalogenated surrogate EChem waste salt using the method proposed in NTRD-MRWFD-2017-000191. The dehalogenated phosphate glass and two annealed samples of the iron phosphate glass were provided for analysis; the two annealed samples were made from glass in the upper and lower portions of the crucible. Both the glass made without the Fe_2O_3 and the upper pour of the iron phosphate glass were light gray and looked glassy, whereas the lower pour was darker, more fractured, and looked slightly crystalline. Modified ASTM C1308 tests were conducted with cuboid specimens cut from the centers of each material and polished to a 600-grit finish using absolute ethanol as a cutting/polishing fluid. The tests were conducted at 90ºC with surface-to-volume ratios near 5 m^{-1} and four 1-day exchange intervals. The phosphate glass made with the dehalogenated salt but without added Fe_2O_3 was almost completely dissolved within the first day and the test was discontinued. Another test was conducted with the glass without added Fe_2O_3 and gave the same result. Only trace amounts of Cl^- were measured in the solutions generated in those tests (2.9 and 1.3 ppm), respectively, which confirms the salt was almost completely dechlorinated. This confirmed the phosphate glass alone is not sufficiently durable to serve as a waste form and that the addition of iron or other stabilizing constituents is required. The results of tests with the annealed specimens of DPF1 made with added Fe_2O_3 are shown in Figure 16. These results show (1) the iron phosphate glass dissolves with linear kinetics, (2) the cations from the salt were retained in the glass, (3) the alkali metals are preferentially leached relative to the iron phosphate glass matrix, and (4) the releases of alkaline earth and rare earth elements are limited by low solubility limits. (Note that every interval in these plots represent the forward dissolution rate because the solutions were replaced daily to minimize solution feedback.) The Li release is similar from both specimens, but the releases of Na, K, Cs, and P are greater from the top pour specimen DPF1a. This probably indicates the melt in the top and bottom of the crucible is not homogenous. In Figure 16c, the releases of Li and Cs from the two DPF1 specimens made with about 27 mass % salt are compared with the releases of these elements from advanced CWF material ACWF-N4-11 made with 11 mass % of a similar salt and from a silica alumina phosphate (SAP) waste form made with a smaller amount of the same salt under the same test conditions. These show Li and Cs are more effectively immobilized in ACWF-N4-11 and SAP than in DPF1, though the mass fractions of both elements are much lower in

those materials: the mass fractions of Cs are about 0.012 in DPF1, 0.0044 in ACWF-N4-11, and about 0.0006 in SAP. The waste cations are immobilized in borosilicate glass in the ACWF and SAP materials and in iron phosphate glass in the DPF materials. Figure 16d shows an SEM image of the polished surface used to assess the composition of the DPF1a material. The EDS analyses at locations shown in the figure indicate the composition is uniform at this scale. The mean and standard deviation of the six analyses are 16.1 ± 0.1 % P, 11.4 ± 0.5 % Fe, 5.5 ± 0.2 % K, 1.7 ± 0.2 % Na, 0.37 ± 0.03 % Cs, and 0.32 ± 0.07 % Ce. The Nd content was not analyzed and Cl was not detected. Similar results were obtained for analysis of DPF1b that indicated the salt was successfully dehalogenated and the salt cations were incorporated into the iron phosphate glass. Analysis of the DPF1 material served as a hold point prior to production of other DPF glasses at PNNL with different salt, phosphate, and iron ratios to confirm the method resulted in an adequate degree of dehalogenation and produced a waste form (milestone M4NT-18AN030105012). Based on the results of these analyses, we recommended production of those other materials proceed to determine the effect of the material ratios on waste form durability. (W. Ebert)

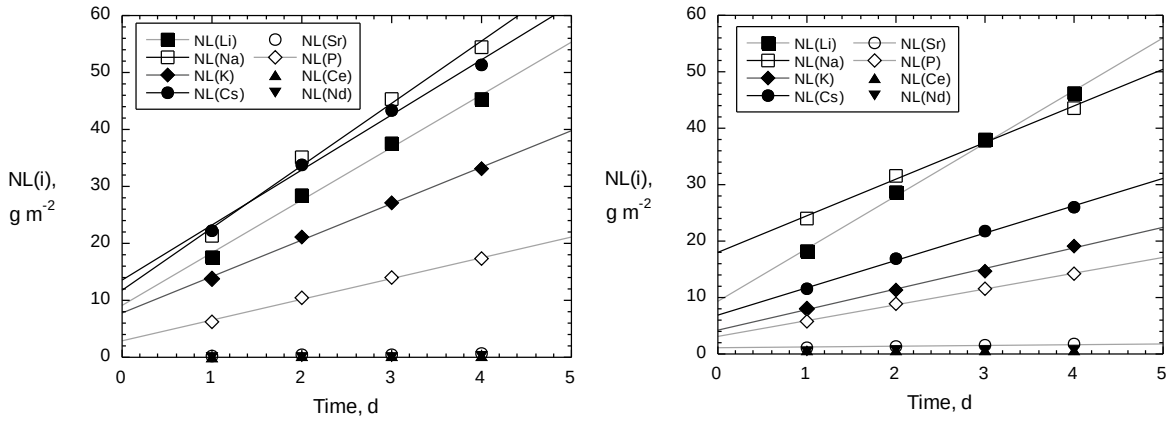

Figure 16. Results of ASTM C1308 tests with annealed samples (a) DPF 1a glass poured from top of crucible and (b) DPF1b glass poured from the bottom of crucible and (c) comparison of alkali metal releases from DPF1a, DPF1b, ACWF-N4-11, and SAP materials, and (d) polished surface of specimen DPF1a.

- **[ANL]** Two manuscripts discussing results of a completed NEUP project supporting alloy and alloy/ceramic waste form development in which ANL collaborated with the University of Illinois at Chicago (Indacochea lead) were accepted for publication: "A U-Bearing Composite Waste Form for Electrochemical Processing Wastes," by *Journal of Nuclear Materials* and "Effect of Molybdenum Additions on the Microstructures and Corrosion Behaviors of 316L Stainless Steel-based Alloys," by *Corrosion Engineering, Science and Technology*. Two other papers based on the NEUP were accepted for presentation at the NACE Corrosion meeting and will be submitted for publication in *Corrosion Science*. (W. Ebert)

Glass Ceramics Waste Forms

- **[LANL]** Hollandite phase as a promising crystalline host for Cs is observed in several multiphase ceramic waste forms. To study the temperature effect on radiation tolerance and determine the critical amorphization dose of hollandite phases, in situ 1 MeV Kr ion irradiations were performed on single phase hollandite samples with various chemical compositions at different temperatures in the Intermediate Voltage Electron Microscopy (IVEM)-Tandem Facility at Argonne National Laboratory (ANL). The IVEM-Tandem Facility is a partner facility of the Nuclear Science User Facilities (NSUF) supported by the U.S. Department of Energy-Office of Nuclear Energy (DOE-NE) for in situ TEM studies of materials under controlled ion irradiation and sample conditions. Ion beam is produced by Tandem ion accelerator which is attached to a HITACHI H-9000NAR microscope. The microscope is operated at 200 kV and the radiation induced microstructural evolution is monitored intermittently by selected-area electron diffraction (SAED) patterns. This research is a collaborative effort with Professor Kyle Brinkman and Ph.D student Robert Grote at Clemson University. Detailed results will be presented in a future report. (M. Tang)

Zirconium Recycle

- **[ORNL]** Custom procurement of glassware equipment from a commercial fabricator was not successful. Therefore, the fabrication will be done by the ORNL glass shop. Parts needed have been ordered. Meetings were held with the 3525 hot cell management to use an existing glove box, with shadow shielding as required, for the purification tests. Adjustments to the safety permit and other pertinent paperwork are in progress. A goal was set to begin cold testing of equipment, including an existing small scale apparatus, by March 1.
- **[ORNL]** Radiation measurements were made on the three bottles of impure $ZrCl_4$ produced by the 2nd large scale chlorination in 2017 and which will be the feedstock for the purification tests. Results are shown in Table 1. (B. Jubin)

Table 1. Radiation measurements of 2017 impure $ZrCl_4$

Sample	Salt Quantity (g)	Dose at Contact (mrem/hr)	Dose at 30 cm (mrem/hr)
Bottle 2-2	96	210-750	13-25
Bottle 2-3	243	80	18
Bottle 2-4	44	36	9

Advanced Waste Form Characterization

- **[ANL]** The results of glass dissolution tests are being analyzed to derive analytical expressions for solution composition dependencies of the dissolution rate that can be used in a degradation model. A few long-term tests remain in progress. (W. Ebert)

- **[PNNL]** Milestone M4NT-18PN030105095, "Submit a paper on the evaluation of hydrated glass to a peer reviewed journal," has been completed by the submission of a manuscript titled "Sol-gel Synthesis and Characterization of Gels with Compositions Relevant to Hydrated Glass Alteration Layers" to the *Journal of Non-crystalline Solids*. The paper explored the thought that if corrosion-generated alteration layers and synthetic silicate gels demonstrate physical and chemical properties that are sufficiently similar, synthetic silicate gels could be used as analogues for hydrated glass alteration layers in future studies. In this study, gels were made with compositions tailored to those observed in alteration layers for several glasses. Each was synthesized at various pH values to evaluate the effect of pH on gel structure and morphology. Several other variables were examined as well, such as composition, drying, and aging. Gels were created by sequential additions of organometallic precursors in a single container. Gels were analyzed with several techniques including small-angle X-ray scattering, gas adsorption, and He pycnometry to determine the effects of the variables on physical properties. Results show that gels prepared at pH 3 consistently contained fewer primary particles with diameters larger than 7.2 nm and fewer pores with diameters larger than 30 nm compared to gels synthesized at pH 7 and 9. Composition was shown to have no discernable effect on primary particle and pore sizes at any pH. An additional paper to be submitted in the next month or two will compare corrosion layers and synthetic gels directly. (J. Ryan)

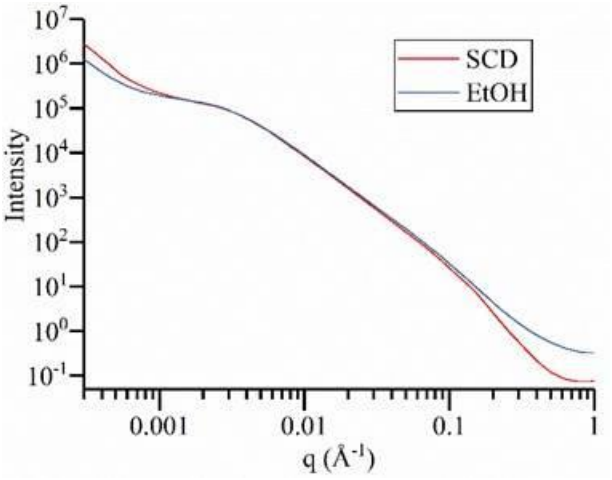

Figure 17. A key finding of the research was that supercritical drying of the gels (SCD) produced structures that only differed from the wet gels (EtOH) at very large and very small particle sizes.

- **[PNNL]** A manuscript titled, "Adaptation of the GRAAL Model of Glass Reactivity to Accommodate Non-linear Diffusivity," by Peter Rieke, James Neeway, Joseph Ryan, and Sebastien Kerisit was completed this month and submitted to the *Journal of Nuclear Materials*. In this work, the equation that controls the gel layer thickness in the GRAAL model was generalized by raising the unitless diffusion term by a power factor p. The manuscript describes this modification and the resulting improvement to the quality of the fits to experimental data on dissolution of nuclear waste glass simulants, as well as the physical basis for this modification. A more detailed description and discussion of the improved model and its application can be found in previous monthly reports and in the FY17 milestone M3FT-17PN030105143. (S. Kerisit)

DOMESTIC ELECTROCHEMICAL PROCESSING

- [ANL] Immersion experiments are in progress to study the interaction of LiCl-Li2O salt with zirconium-based cladding. Coupons of Zr metal are being corroded at 650 C in salts with between 0 and 10 wt % Li2O contents to assess the effect of the O2- activity on the corrosion rate. The Zr

corrosion rates are being determined from the Zr concentrations in the salt that are measured daily over a 6-day test duration. Figure 18 shows corroded coupons that had been suspended in the furnace and immersed about half way into LiCl (left) and LiCl-1 wt % Li2O (right) salts. Corrosion was most extensive at the salt/vapor interface on both specimens and is more aggressive in the salt containing Li2O. (W. Ebert)

Figure 18. Zr coupons reacted in LiCl (left) and LiCl-1 wt%Li_2O (right) at 650°C for 6 days.

SIGMA TEAM FOR OFF-GAS

- **[INL]** Iodobutane adsorption testing using silver zeolite sorbent was started in early December and continued through January. Testing was shut down during the Christmas break and for about three weeks in January due to project and travel needs. This test will continue into February to obtain sufficient run time to have some confidence that the goal of reaching the practical iodine saturation level in at least the Bed 1 sorbent is achieved. It was noticed that, even after this test continued for over 200 hours, no increase in sorbent bed outlet iodobutane was observed. Perhaps the silver zeolite/NOx gas conditions more completely destroys the iodobutane than did the silver aerogel in the most recent prior test; or perhaps there is a gas chromatograph retention time shift. Testing continues while the test data is assessed to address this. Either way, the test results will still indicate the silver zeolite performance for capturing the iodine in iodobutane. (N. Soelberg/A. Welty)
- **[INL]** A teleconference was held on January 22 to initiate development of the test plan for performing long-chain organic iodide testing for vessel off-gas (VOG) conditions. This teleconference initiates work by INL to meet a Level 4 INL milestone due on February 28, 2018 to assist ORNL in the preparation of this test plan. (N. Soelberg/A. Welty)
- **[ORNL]** Testing associated with the milestone to complete testing of integrated iodine scrubber and polishing bed system has required system upgrades of the NO_2 delivery system and the procurement of an additional NO_2 gas cylinder. That cylinder has been received. The system upgrades are proceeding on schedule. (B. Jubin)
- **[ORNL]** The milestone report (NTRD-MRWFD-2018-000200; ORNL/SPR-2017/576), "Performance of Ru removal systems in prototypical TOG streams," was submitted on 1/31/2018. The tritium pretreatment process will release a fraction of the ruthenium as volatile ruthenium tetroxide (RuO_4). Scoping tests were conducted to characterize the adsorption/deposition of RuO_4 from dry gas streams by two different substrates: steel wool and silica gel. A simple test system was assembled to produce RuO_4 through oxidation of powdered ruthenium metal, followed by a temperature-controlled sorption column. Both steel wool and silica gel are able to decrease the

effluent Ru concentration by a factor of 10–100 during the 5-hour tests conducted. These tests were conducted using a dilute RuO_4-bearing dry gas stream and the short test duration did not result in sorbent saturation or in an estimation of Ru breakthrough time. RuO_4 desorbs from silica gel at room temperature. As interactions between RuO_4 and silica gel are not irreversible, it cannot function as a disposal media without pretreatment to reduce RuO_4 to a less mobile species. Silica gel may be useful as a RuO_4 sorbent or delay media in some applications. Based on visual observations, steel wool was an effective deposition substrate with no evidence of RuO_4 release. (B. Jubin)

- **[ORNL]** The milestone report NTRD-MRWFD-2018-000199; ORNL/SPR-2018/15, "Testing of an iodine and tritium removal system for advanced tritium pretreatment," was submitted on 1/31/2018 and is summarized below. (B. Jubin)

  Up-front removal of tritium from the fuel in a pretreatment step, followed by the abatement of tritium from the advanced tritium pretreatment off-gas (ATPTOG) stream, can minimize or eliminate the distribution of tritium throughout the plant, also decreasing or eliminating the need for tritium capture on multiple off-gas streams. The use of NO_2 as the oxidant allows tritium pretreatment to be performed at lower temperatures and may result in the quantitative release of iodine from the fuel. The ATPTOG will contain up to 75 vol% NO_2 gas. In a previous report, Spencer et al. identified the most promising iodine sorbent as silver nitrate–impregnated alumina (AgA) and the most promising tritium sorbents as 3A molecular sieve (3A MS) and silica gel for radionuclide capture from ATPTOG streams. A total of five tests examined AgA as a potential iodine sorbent at an operating temperature of 150°C and both 3A MS and silica gel as potential tritium sorbents with an operating temperature of 40°C. 3A MS and silica gel are intended for use as regenerative sorbents, in which the adsorbed tritium (as tritiated water or tritiated nitric acid) is loaded onto the sorbent at operating temperature and then subsequently desorbed at high temperature into a small-volume gas stream for recovery and conversion to a waste form. Analysis of the test materials showed that much of the tritium and iodine delivered during testing was not recovered on the solid sorbent test materials or liquid scrubbers used in test execution. The cause of this discrepancy was identified during system disassembly, in which a system component was found to be corroded. Analysis of the corroded component found that it contained both iodine and tritium. The loss of tritium and iodine to the test system negatively impacted the ability to draw quantitative conclusions regarding the adsorption of tritium by either silica gel or 3A MS in high NO_2 systems. Residual tritium was found on both the iodine and tritium sorbents at the end of each test. The ability of AgA to adsorb iodine in the presence of high levels of NO_2 appears to be substantially reduced upon exposure of the sorbent to NO_2, with replicate testing showing variable iodine recoveries on the sorbent of 29.6% and <0.1%. Given the corrosion observed during testing, the performance of AgA should be reexamined with a more robust system. These initial tests, however, do indicate a failure of the sorbent to perform to the levels that would be required in an ATPTOG treatment system.

- **[ORNL]** An experimental test plan was developed to support the effort to quantify the potential physisorption on silver based sorbents that was potentially observed in FY 17 VOG testing. The test matrix is shown in Table 2. A test examining the potential physisorption of CH_3I by AgZ with CH_3I concentrations of 200 ppb has been initiated. (B. Jubin)

Table 2: Test Matrix: Characterize physisorption of CH_3I on AgZ sorbent beds

Species	Concentration	Test Duration (h)
I_2	10 ppm	4
I_2	100 ppb	400
CH_3I	20 ppm	4
CH_3I	200 ppb	400
CH_3I	TBD	TBD

- **[PNNL] A** series of batch experiments to scale up the best performing CaSDB for INL deep bed measurements was completed. Experiments are in progress to obtain the engineered particles of CaSDB MOF. (P. Thallapally)
- **[PNNL]** A level five milestone M5NT-18PN030107034, "Supply Ag^0-Functionalized Silica Aerogel to INL," was completed for DOE-NE project "Development of Ag^0-functionalized silica aerogel (Ag-aero) for capturing and immobilization of radioiodine from reprocessing off-gas." A total 150 g of Ag-aero granules was produced at PNNL through functionalization of temperature strengthen silica aerogel. The granules were larger than 0.85 mm and had a bulk density of 487 kg/m^3. The sorbent exhibited iodine sorption capacity of 412.0 ± 0.7 mg/g after exposure to iodine vapors at 150°C for 96h. This indicates a silver concentration of 350.2 ± 0.6 mg/g, assuming a full utilization of silver during this test. The material was shipped to Idaho National Laboratory for deep bed sorption testing in various off-gas streams.

  An effort is underway to optimize synthesis of silver nanoparticles on thiolated silica aerogel (SH-aero) support with a goal to further improve sorption performance of Ag-aero and strengthen resistance of the sorbent to aging. The recent study revealed the effect of increased concentration of $AgNO_3$ and drying time under fluorescent light on morphology and quantity of silver inclusions. At low concentration of $AgNO_3$ single silver atoms formed and were anchored to S. However, increased concentration of $AgNO_3$ resulted in agglomeration of silver atoms into 5-10 atom clusters. These clusters condense into silver nanoparticles (<2 nm) with time when exposed to light. The light reduction process was much faster for high concentration solution of $AgNO_3$, producing large number of silver nanoparticles (<6 nm). Figure 19 visualizes single Ag atoms, Ag atom clusters and Ag nanoparticles found on pores surfaces of SH-aero after exposure to $AgNO_3$ solutions of different concentration. (J. Matyas)

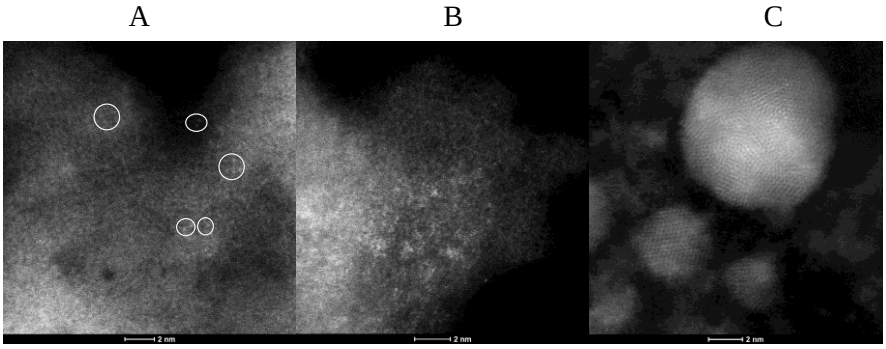

Figure 19. TEM images of single Ag atoms (A), Ag atom clusters (B), and Ag nanoparticles (C).

FLOWSHEET DEMONSTRATIONS

- **[PNNL]** The initial results from the CoDCon flowsheet test conducted in November 2017 were communicated to DOE-NE. The average U/Pu mass ratio in the aqueous product stream from the CoDCon solvent extraction circuit was 6.1/3.9 which was lower than the target value of 7/3. The low U/Pu ratio resulted from an overestimation of the U(VI) concentration indicated by the on-line monitoring system. Off-line analysis of grab samples also showed that the U and Pu concentrations indicated by the on-line chemometric model were biased low. Refinement of the calibration transfer protocol for the on-line monitoring should correct this issue, and these refinements are in progress.

  Although the average U/Pu mass ratio achieved was lower than targeted, the ratio was maintained within 3% of the average value throughout the course of the experiment. In one stretch of ~1.5 h, the ratio varied ≤ 1%. The major drifting from the average value appeared to be attributed to unplanned

variations in the flowrate of the U/Pu loaded TBP solvent. More consistent control over this flowrate should reduce the variation in the U/Pu ratio. (G. Lumetta)

- **[INL]** The two main process skids were delivered at the end of December and have since been moved into position and the remainder of the Perma-Con enclosure that surrounds them has been installed. This will allow the subcontractor to begin all of the piping and electrical connections that need to be made between the skids and other equipment. The sprinkler installation was also completed inside of the Perma-Con enclosure bringing the building and enclosure into compliance with fire protection codes. In addition to this work, the monorail crane/hoists on the main process skid have been successfully load tested. This will allow us to use the crane/hoists during the Functional Acceptance Testing at the end of March and will allow us get our hoisting and rigging training completed for those hoists. (M. Warner)
- **[ANL]** Analysis data has been received from PNNL from the CoDCon demo, and we have started running simulations using the AMUSE code. Initial runs suggest a lower U: Pu ratio than predicted given the operating conditions of the test, but further analysis is required to verify. We will perform a parametric analysis to bracket the expected performance based on the process models. (C. Pereira)

For more information on Material Recovery and Waste Forms Development contact Terry Todd (208) 526-3365

MPACT Campaign

MANAGEMENT AND INTEGRATION

Management and Integration

- **[INL]** Coordinated planning of Spring Working Group Meeting to be held at INL, March 20-22, 2018. Planned and coordinated testing of the LANL developed High Dose Neutron Detector at INL.

SAFEGUARDS AND SECURITY BY DESIGN - ECHEM

Modeling and Simulation for Analysis of Safeguards Performance

- **[ANL]** Developed kinetic and thermodynamics-based calculations to describe distillation and evaporation rates of the various molten salt components under vacuum and at atmospheric pressure with a purge gas. These are applicable to unit operation models involving salt separation from metals (i.e. salt distillation from cathode deposits, used anode baskets, reduced fuel prior to electrorefining) and for quantifying salt losses from process vessels (reducer, electrorefiner, drawdown) and their effects on process salt concentrations.

Voltammetry

- **[ANL]** Work on constructing the multielectrode sensor has been completed. Installation of low-noise, low-impedance wiring into the glovebox is presently being performed, after which the sensor will be installed into the PEER electrorefiner. A milestone report for Task M3NT-18AN040104021 (Finalized Voltammetry Sensor Design and Construction) was submitted.
- **[INL]** The experiments monitoring Li2O composition in LiCl-Li2O molten salt with the two different reference electrodes (Ag/AgCl and Ni/NiO) were completed. Based on these experiments' results the voltammetry probe will use a Ni/NiO reference electrode. The fabrication of the new mock-up probe has been completed in preparation to assemble the tungsten and platinum electrodes into the probe and to fill some NiO powder into the Ni/NiO RE cavities in the probe to make the voltammetry probe functional.

Sensor for Measuring Density and Depth of Molten Salt

- **[INL]** An experiment was performed with a CsCl-LiCl molten salt in a 2 zone furnace to determine correction factors for density and surface tension. The results of this experiment are being analyzed. A small dent was observed on one of the bubbler tubes after this experiment. A series of tests with water was performed and the calibration factors aligned with the ones calculated last summer, indicating that the bubbler had not been compromised. An experiment was also performed using a LiCl-KCl molten salt. The results are being analyzed.

Electrochemical Signatures Development

- **[LANL]** Mesh-tally plot animation: Capability has been developed to make animated movies of MCNP6 mesh-tally data using gnuplot and GIMP. Animations of mesh-tally data for the moving WFA/PEER/TCATH and ABTR/MK4/LCC electrochemically processed sources models in the reference hypothetical pyroprocessing facility were created. These models include the High Dose Neutron Detector (HDND) model developed by Drs. Daniela Henzlova and Howard Menlove. This work marks the first time that animations of simulated moving radiation sources emanating from electrochemically processed spent fuel have been produced. Benchmarking using measured data: Drs. Henzlova and Menlove are working on acquiring measured data for their 252Cf and 137Cs

sources set in motion using the HDND. These investigators were provided with descriptions of the kinematic capabilities for the MCNP6 moving-objects code. Should this data become available, validation efforts will be undertaken. Such efforts will constitute seminal validation of the moving-objects capability.

ADVANCED INTEGRATION

Advanced Integration (Methods)

- **[LANL]** A first spectrum was generated from Microcal. Began to work through the data with statisticians for our integration effort to determine Pd's for notional diversions.

EXPLORATORY RESEARCH / FIELD TESTS

Microcalorimetry

- **[LANL]** Analysis of data from the December measurements has continued in collaboration with University of Colorado. A major result is the first microcalorimeter gamma spectrum of a small spent fuel sample. Despite the very low activity of the sample, the stability of the system was sufficient to collect a spectrum with 3 million total counts over 90 hours. This first measurement of its type is being studied in the Advanced Integration project to evaluate potential detection of diversion in a direct spent fuel measurement. Energy resolution was approximately 60 eV FWHM at 100 keV for one half of the array, but 100 eV for the other due to the attenuation problem. With the cryostat system warm, we found that the anomalous attenuation problem on one microwave channel was caused by a failed HEMT amplifier. With the amplifier replaced, the microwave transmission on both circuits appears to be correct at room temperature. Modeling of the magnetic shield indicates that performance can be improved by simply repositioning the detector array inside the shield. Cryogenic testing in February will be needed to confirm. Katrina Koehler led a full-day thesis review meeting with participants from LANL and Western Michigan University. Derivation of key components of the electron capture spectrum models, calculation methods and code structure, possible choices and approximations, and future work were discussed.

In situ Measurement of Pu Content in U/TRU Ingot

- **[INL]** The facility procedures for conducting melting point tests in the Hot Fuel Examination Facility (HFEF) have been completed. The U/TRU product from the fourth JFCS liquid cadmium cathode operations has been produced (see attached Figure) and weighed approximately 100 g. Following other JFCS work at window 10M in HFEF, the U/TRU product will be melted and cooling curve analyses will be performed to discern the plutonium content of the product.

High Dose Neutron Detector

- **[LANL]** Interactions with INL on scheduling and logistics of the field test are ongoing. INL provided list of materials available for measurements and LANL is preparing cabling to support HDND installation. Initial measurements of moving source response of HDND were performed at LANL with 252Cf and 137Cs neutron and gamma sources.

For more information on MPACT contact Mike Miller at (208) 526-2813.

Fuel Cycle Options Campaign

CAMPAIGN MANAGEMENT

- **[ANL]** Participated as a member in the First Meeting of the Scientific Advisory Committee charged with the technical program for the Fifteenth Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation, at the OECD/NEA Headquarters, Paris, January 16-17, 2018.
- **[ANL]** Participated in the DOE NE-4 Steering Committee Meeting to discuss the objectives and Agenda for the February 1, 2018 meeting focusing on the alignment of the reactor campaign R&D work packages to the needs that have been communicated to DOE NE by the NEI reactor working groups.

EQUILIBRIUM SYSTEM PERFORMANCE (ESP)

- **[INL]** Participated in a meeting of the NEA Expert Group on Back-End Strategies (BEST) at the OECD/NEA Headquarters, Paris, January 17-18, 2018. This expert group is developing a report for decision-makers on the primary considerations to address in developing or updating a back-end strategy and summarizing the strategies proposed or being used by different countries.

Performance of Fuel Cycle Systems

- **[ANL]** Collected information on the Molten Salt Thermal Wasteburner (MSTW) that is under development by Seaborg Technology, Denmark. The MSTW is a 100 MWe molten-salt reactor with graphite moderator (i.e., molten fuel flows through graphite structures). The fuel is eutectic sodium-actinide fluoride salt mixture. Initially, the actinide fuel mixture is 93% thorium, and 7% pre-processed spent nuclear fuel (SNF) with 3.5% reactor-grade plutonium, but over time only SNF is added, the plutonium "quality" decreases, and the thorium fraction decreases. The proposed fuel cycle is limited recycle of Pu/Th with new enriched-U/Th fuel in thermal reactors (EG17).
- **[BNL]** Review of fuel cycle fact sheets developed by BNL in FY16 and FY17 is underway. Have started looking at information on "Fuel cycle(s) of Russia".
- **[INL]** Working on the review of reactor design and fuel-cycle characteristics for U-Battery®. It is an intrinsically safe small-modular gas-cooled high-temperature reactor developed mainly by TU Delft and University of Manchester with support from URENCO. The core is based on standard graphite based HTR fuel blocks utilizing TRISO particles as a fuel and designed to have very small core size producing only 10-20 MWth over the period of 5-10 years.
- **[ORNL]** Further work has been completed on the generation of physics data and assessment for the MSR transition analysis. This has included generation of mass information and cross sections from the fast spectrum molten salt reactor systems to perform fuel cycle analyses in ORION. The analysis has included working with the ORION developer to help clarify some physics aspects of molten salt reactors that should be accounted for in a fuel cycle analysis code. This included technical direction on the methods of accounting for continuous feed and removal of materials within depletion solvers.

Economic Analysis Capabilities and Assessments

- **[INL]** Completed export control review of the 2017 Cost Basis report in preparation for its public release. Completed a detailed redline review of the document to ensure completeness of references and addressing formatting, numbering, and cross-reference issues.
- **[ANL]** Completed the development of the code for the calculation of the containment cost for cylindrical containments, and wrote the corresponding section of the report. The containment cost

code has been fully tested by comparing to results of the EEDB, and debugged. Separately, the NSSS cost breakdown approach utilized in the FY17 cost algorithm report was revised. That information is to be used to compare to a breakdown of the NSSS of the LMFBR found in a report by Combustion Engineering (CE) from 1978. Additionally, some details of the costing logic for certain equipment of the NSSS of the LMFBR are available in the CE report. Unfortunately, the corresponding data for the System-80 are not provided, since they were likely treated as commercial secrets.

- **[ORNL]** A draft of the milestone "Report Identifying the Value Added by Fuel Cycle Dynamics Tools Directly Using Cross Section Data" has been completed and issued to Campaign management and lab leads for comment. Comments have been received and are now being incorporated into the final report prior to submission to the sponsor on February 9th.
- **[ANL]** Contact was successfully established with the President of North American Forgemaster, in order to gain access to relevant information on the cost of fabrication of ultra-large forged components, and perhaps even more importantly, to establish cost models for those components. A non-disclosure agreement between ANL and North American Forgemaster was established and fully executed by both parties, so that the conversation on costing on components can be initiated. Separately, the correspondence with Holosgen continued, in order to identify large forging costing models.
- **[ANL]** Led conference calls of the Cost Basis Report (CBR) working group, where progress by the group was discussed and tasks were defined and assigned. Developed a draft write-up including the quantitative analyses performed on metallic fuels based on the data that was found so far. Additionally, with a focus on the primary tasks identified in the language of the work package, the following tasks were initiated:
  - Revise the write-up on metallic fuel, and identify possible improvements and necessary future work.
  - Revise write-ups from FY17 on modules F2/D2 and F1 and suggest work that need to be performed to improve those modules, starting from what has already been done.
  - Start work on cost of DUPIC, since (a) limited cost data was found in the literature, (b) this limited cost information may provide insight in the cost of remote fabrication, since DUPIC needs to be fabricated remotely, (c) no cost basis currently exist for DUPIC in the CBR.
- **[BNL/PSU]** Importer templates for EG01 and EG30 are in the final stages of revisions and will soon be delivered to ORNL for implementation into a database template. Several internal iterations and checks have been made to the importer templates to assist in capturing all of the data from the FCDP. The importer templates now include some new information, including references; however, approximately 90% of the template maintains the same nomenclature and data as the original version. A glossary of terms, acronyms, and calculations has been built with the goal of transforming this into a "user's manual" of the new transmutation library. Additionally, scripts have been built that allow for easier implementation of isotopic data into the new importer templates. An investigation is underway to fully understand if scripting can fully automate the process of transferring information from the legacy transmutation library into the current importer template. This investigation will likely signal that the importer template will need to be altered for importing information from the legacy transmutation library. Immediate action items include sending completed importer templates of EG01 and EG30 to ORNL for initial database implementation, finalizing importer templates for EG04, EG29, and EG39, and researching MySQL, the database management system for this project
- **[INL]** Began revision of the front end modules for the Cost Basis Report update. This included editing revised drafts of the document and re-routing revisions for inclusion into the upcoming release. Also started working on the revisions for the front end modules in anticipation of the next

CBR update. These revisions also include review of the back end modules in order to identify ways to update module content.

Equilibrium System Performance (ESP) Tools Development

- [**ANL]** In order to acquire an energy market analysis capability, received training on using the EDGAR (Economic Dispatch Genetic AlgoRithms) that is under development in ANL. This code optimizes the power output of the 65 plants in the APS (Arizona Public Service) over a whole year to meet demand and reserve constraints while minimizing the cost of electricity generation.
- **[ORNL]** Work has continued on the development of the transmutation database, including confirmation of the final scope, and allocating the activities amongst ORNL and Penn State University (PSU). The additional scope confirmed at the last meeting includes the development of a MySQL database schema by ORNL, and the review of the database by PSU.
- **[BNL/PSU, ORNL]** Work continued on developing importer templates for EG01, EG04, EG29, EG30, and EG39 for the transmutation library. Several iterations of internal checks have occurred at PSU to verify the information entered into the importer templates. This process has led to implementing additional information and calculations into the importer template to fully capture the data presented in the FCDP. These descriptions and calculations will be better defined in an effort to create a "user's manual" for the new transmutation library. Once a few templates are internally verified (EG01 and EG30), ORNL will create a database template. PSU will then begin to populate the database template with data from all 40 EG fuel cycles. Bi-weekly meetings are held between BNL/PSU and ORNL to discuss progress and answer any questions. These meetings also help to clarify the overall scope of the project and plan for future deliverables. PSU will also continue to finalize importer templates for EG04, EG29, and EG39.
- **[ANL]** Significant progress was made in the finalization of the NE-COST website. A meeting was held at ANL on Feb 25th, with FCO ANL personnel and the campaign NTD in order to identify tasks necessary for the finalization of the website. The implementation of the identified changes is now nearly complete, through several meetings and phone calls with the person developing the website.
- **[SNL]** All fuel cycle options that were given to us to enter into the public fuel cycle options catalog have been verified and entered, and are available in the public fuel cycle options catalog

DEVELOPMENT, DEPLOYMENT AND IMPLEMENTATION ISSUES (DDII)

- **[INL, BNL, ANL, LLNL]** The accepted paper, "Technology and System Readiness Assessment for a Nuclear Energy R&D Program" was submitted for peer review for the Portland International Center for Management of Engineering and Technology 2018 conference (PICMET'18), August 19-23, Honolulu, HI. The paper describes the history of and drivers for the DOE Guide for technology readiness assessments, and how FCO has augmented that guide for application to nuclear R&D and used it in trial applications.
- **[ORNL]** An abstract on "The Economics of Transition and Deployment: An Advanced Fuel Cycle Cost Analysis Using ORION" has been produced for the Pacific Basin Nuclear Conference (PBNC 2018), Sept. 30 - Oct. 5, 2018, San Francisco, CA. The objective of this work was to determine whether a dynamic fuel cycle modeling tool such as ORION can provide further insight into the economics of transition between fuel cycles. An additional objective was to engage a post-doc researcher into the Campaign who had expressed an interest in fuel cycle economics, and had a background in related fields.

Technology and System Readiness Assessment (TSRA)

- **[INL, ANL, BNL, LLNL]** An informal status discussion with DOE-NE was conducted on January 9th to provide information on the approach and progress to date. Top level characteristics and assumptions of the example system to be evaluated for the June milestone were provided (e.g. metallic fueled sodium-cooled fast reactor, electro-chemical processing, ready for deployment in 2040, etc.). As follow-on to the discussion, a half-page summary of the effort was generated for DOE staff's use in communication within NE.
- **[INL, ANL, BNL, LLNL]** The general system description of the example system to be used for the TSRA assessment of a complete fast reactor recycle system was completed through joint work of the FCO, Advanced Fuels, Material Recovery and Waste Form Development, Fast Reactors, and MPACT campaigns.
- **[INL, BNL, ANL, LLNL]** Regularly scheduled telecons have continued to discuss and plan the TSRA activities for FY18, including finalizing updated questionnaire for Technology and Systems Readiness Levels and updating the June 2016 report to reflect the "lessons learned". The plan is to apply the TSRA process to the evaluation of EG24 (continuous recycle of transuranics in a fast spectrum) from the Evaluation and Screening Study.
- **[INL, BNL, ANL, LLNL]** The TSRA team developed an approach for ordering the TRLs in the planned revision of the TSRA report, "Technology and System Readiness Assessment Process for R&D Evaluation, FCRD-FCO-2016-000110, June 30, 2016, into subject tracks (e.g., "Requirements and Assumptions", "Safety, Environmental Compliance"). As part of this "ordering" some additional questions have been proposed, as well as modifications to the wording of some of the initial TRL questions. The "base/reference" questionnaires are being updated to include inputs from this approach.
- **[INL]** Completed refinement of technology readiness level (TRL) questions and tracks to ensure each level addresses all of the topics in lower levels. This will facilitate the analysis of technologies which enter the evaluation process in a partially mature state by eliminating the need to start the evaluation at TRL1. Refining system readiness level (SRL) questions to provide flexibility and completeness similar to the TRL questions. Met with TSRA computer tool development team to discuss ideas for the structure and capabilities of the tool.
- **[LLNL]** Provided review input for draft "Technology and System Readiness Assessment" process text and questionnaire tables that are being developed for application to an entire advanced nuclear fuel cycle.

Transition Analysis Studies

- **[ANL, ORNL]** Held a teleconference call on Jan. 24, 2018, to discuss the technology characteristics of transition from EG01 to a promising fuel cycle (EG24) with SFRs and MSRs. In order to evaluate MSR design variations, ANL and ORNL agreed to do transition analyses using two MSR concepts that were developed by ANL and ORNL. In addition, ANL and ORNL agreed to assess the differences in startup inventories, reprocessing time, and breeding ratios between the SFRs and MSRs. Preliminary transition calculations have been performed.
- **[ANL]** Additional refinements to the EG24 MSR core model were made (50% FP removal, 90% Cl-37 content, lower initial enrichment of LEU, etc.) and the startup and refueling mass flows and fuel compositions were regenerated. These data were then used as input in the DYMOND fuel cycle systems code to simulate transition from EG01 (once-through LWRs) to a continuous recycle system with MSRs (EG24-MSR).

- **[ANL]** The DYMOND simulations showed that the front-end requirements (NU and enrichment) depend heavily on the assumed fuel salt inventory of the first MSR (both inside the core and outside in the loops through heat exchanger, separation loops, etc.). For most fuel salt MSR designs from commercial startups, the total inventory is up to twice that inside of the active core. The specific EG24 MSR designed by ANL is a single datum point within a wide spectrum of potential EG24 MSR performance, but is very informative on the reactor and fuel cycle design characteristics that impact the transition performance. Currently, ORNL is reviewing this MSR design and will be sharing their own EG24 MSR design with different characteristics to further sample the performance spectrum. A general comparison of transition and performance characteristics of the EG24 MSRs will be made to those of the EG24 SFRs
- **[ANL/INL]** The M3 report, "Value Added by Fuel Cycle Dynamics Tools Directly Using Cross Section Data" drafted by ORNL, was reviewed and comments were provided to ORNL.
- **[INL]** Conducted the analysis of the case of EG23 transitioning to a closed fuel cycle using the economic model he developed in December. Sent the model and analysis for review of the work. After discussions with INL staff we are now updating the economic model to correct for errors in how the input data was read in, and to adjust cost parameters.

Regional and Global Analysis

- **[PNNL]** Attended OECD/NEA Expert Group meeting on Advanced Reactor Systems and Future Energy Market Needs in Paris, France. Gave presentation on nuclear energy scenarios exploring a range of issues affecting nuclear energy use, such as renewable energy penetration, energy storage, carbon mitigation, capital costs, nuclear lifetimes, etc.

Development, Deployment, and Implementation Issues (DDII) Tools Development

- **[ORNL]** Preliminary testing has been completed of cross section libraries and in-line ORIGEN-ORION runs for modeling MSRs. These results have been documented and shared with the developer, UK National Nuclear Laboratory, to ensure the validity of the model and the accuracy of the results being generated.
- **[INL]** Upgrades to the input and output files of the VISION model have been implemented and are now being tested and documented. These changes simplify the development and management of scenarios and enable the user to vary the temporal scope of the simulation. This included expanding the capability of VISION to model scenarios greater than 200 years in length; scenario length is now unlimited. A study of alternative methods for managing recovered uranium within the VISION model also continues.

For more information on Fuel Cycle Options contact Temitope Taiwo (630) 252-1387.

Joint Fuel Cycle Study Activities

- Completed the documentation of the Nuclear Technology transferred in 2017. This completed the level 2 milestone "Prepare 2017 Nuclear Technology Transfer Documentation."
- Process experiments for the fourth U/TRU recovery into liquid cadmium were initiated. This test was performed using a traditional approach of driven-deposition into a liquid cadmium cathode.
- Analytical results were received for samples from the first three U/TRU recovery experiments. These analyses are being used to complete the fuel experiment analysis for irradiation in the advanced test reactor.
- Casting of the master alloys (blends of zirconium and uranium) for fuel fabrication has been initiated. Transfer of the master alloys into HFEF and then casting of the fuel slugs for ATR irradiation are expected to occur in February.

For more information on Joint Fuel Cycle Studies Activities contact Mike Goff (208) 526-1999 or Ken Marsden (208) 533-7864.

AFCI-HQ Program Support

UNIVERSITY PROGRAMS

Site: University Research Alliance at West Texas A&M University in Canyon TX, and the following universities: University of Michigan, University of Tennessee, University of California at Berkeley, Massachusetts Institute of Technology, University of Utah, Rensselaer Polytechnic Institute, Washington State University, Colorado School of Mines, University of Nevada at Las Vegas, Clemson University, University of South Carolina, Purdue University, and other universities.

Universities engaged in Nuclear Technology research via URA programs since 2001:

Boise State University
Boston College
Clemson University
Colorado School of Mines
Georgia Institute of Technology
Idaho State University
Florida State University
Kansas State University
Massachusetts Institute of Technology
Missouri University of Science and Technology
North Carolina State University
Northern Illinois University
Northwestern University
Ohio State University
Pennsylvania State University
Purdue University
Rensselaer Polytechnic Institute
Rutgers University
Texas A&M University
University of Arkansas
University of California at Berkeley
University of California at Santa Barbara
University of Chicago
University of Cincinnati
University of Florida
University of Idaho
University of Illinois at Urbana-Champaign
University of Michigan
University of Missouri
University of Nevada at Las Vegas
University of New Mexico
University of North Texas
University of Notre Dame
University of Ohio
University of South Carolina
University of Tennessee at Knoxville
University of Texas at Austin
University of Virginia
University of Wisconsin
Vanderbilt University
Virginia Commonwealth University
Washington State University

INNOVATIONS IN NUCLEAR TECHNOLOGY R&D AWARDS

Summary Report

- University Research Alliance completed preparations for the 2018 Innovations in Nuclear Technology R&D Awards (formerly the Innovations in Fuel Cycle Research Awards). The timeline for the 2018 awards was finalized and the web site updated.
- The DOE requested the same categories for this year's awards as last year. No changes were made to the award categories.
- The program was announced on January 29. The announcement was made through emailing information about the program to university faculty in relevant disciplines.
- University Research Alliance conducts a significant outreach effort to acquire the applications. The announcement is sent to more than 24,000 faculty in relevant disciplines at universities throughout the United States. The announcement is also sent to a number of web sites including the American Nuclear Society, the Nuclear Energy Institute, and science.gov. It is also sent to ANS student chapter

presidents, INMM student chapter presidents, and university research centers that conduct nuclear technology research. Students and their advisors who have won awards in previous years are informed of the opportunity so that they may apply again, if eligible, and pass the information on to their colleagues. Announcements are sent to nuclear engineering department heads and faculty who are known to be conducting nuclear technology research. The objective is to ensure that every student who may be eligible for an award is informed of the opportunity. The number of applications has increased by about 25% over the past three years, but the pool of potential applicants is still a small pool. The number of applicants is significantly affected by the amount of research any one faculty member may be conducting, and the research stage.

- The announcement will be sent to all parties several times to provide every eligible student the opportunity to apply.
- Historically, the vast majority of applications are received in the final week, with most of those being received in the 24 hours before the deadline.
- University Research Alliance has been removing email addresses for rejected announcement emails and removing addresses of people who have asked to be unsubscribed from the list. This process will continue with each announcement.

For more information on the University Research Alliance contact Cathy Dixon (806) 651-3401.